Toward a U.S. Plan for an Integrated, Sustained Ocean Observing System

Executive Summary

The oceans are central to the history, health, economy, security, and future of this nation. Knowledge of the ocean—globally and especially in our coastal areas—is demanded by many constituencies, including climatologists, fishermen and fisheries managers, harbor pilots, coastal zone managers, Navy and Coast Guard commanders, Public Health Service officers, environmental protection professionals, commercial and recreational boat and ship operators, weather forecasters, and the offshore mining and oil industry.

Many of these needs are being partially met by existing ocean observing system elements, both satellite and in situ. These have not developed in an integrated manner and have been funded and operated to meet their own purposes. Some of these elements are in danger of disappearing, even though their needs remain, while other useful elements could be deployed for broad applicability, but there is no clear route to testing, maturity, funding, and operational implementation. In short, the need for national ocean information is similar to the need for national weather information—it serves the broad public good. Unlike weather information, however, a considerable fraction of the existing ocean observations is funded, managed, and utilized by many different groups, agencies, institutions, and individuals, for as many purposes. Thus, a key issue for a national ocean observing system is integration of disparate observational systems and data sets to maximize their utility for many users and purposes. Studies to date indicate that ocean observing elements have a return on investment that is substantial, which can be further increased by more cost-efficient integration of data sets and shared use of observational platforms.

Three dominant actions leading to the desired observing system are:
1. sustain existing (and new) ocean observations;
2. integrate existing (and new) ocean observations; and
3. adapt the system to meet evolving needs, including recommendations for development of new technologies to make sustained ocean observations more complete, more effective, and more affordable.

Four critical issues, underlying these three actions, are:
1. funding of ocean observing and data management activities;
2. organization and management of the activities;
3. integrated data management; and
4. exploiting the complementary interests and expertise of the academic, industrial/private, and governmental sectors through appropriate partnerships.

This report addresses seven major societal needs (not prioritized), thus setting the high-level objectives for an integrated, sustained, national ocean observing system:
1. Detecting and forecasting oceanic components of climate variability.
2. Facilitating safe and efficient marine operations.
3. Ensuring national security.
4. Managing living resources for sustainable use.
5. Preserving healthy and restoring degraded marine ecosystems.

6. Mitigating natural hazards.
7. Ensuring public health.

Two cross-cutting objectives are: use of ocean data for education and public awareness, and use of ocean data to support scientific research. The degree to which the seven objectives listed above can be achieved is determined by the level of understanding of the natural and anthropogenic phenomena that control the ocean system. In some areas this understanding is well advanced allowing effective use of ocean observations for immediate societal benefit today. In other areas, our understanding is limited and research is required to understand the processes that control changes in the ocean and in the climate. This research requires long-time-series data sets to validate models and provide new insights into the causes of the oceans variability. Thus, ocean observations are justified both by their immediate practical utility and also by their role in facilitating new understanding through research, which is the essential foundation upon which more complete achievement of the seven objectives is built.

Elements of a national ocean observing system already exist. However, the paramount issues of continuity, integration, and evolutionary improvement must be addressed. The recommendations address actions that will enable immediate improvements to the existing observations and associated data management, ensure continuity of critical observations, lead to integration for maximal shared use of platforms and data, and foster coordinated planning and implementation.

All of the included recommendations have been through a vetting process in the scientific and ocean-data-user communities, as documented in reports from the National Academy of Sciences, the planning components of the Global Ocean Observing System, and other broad-based consensus processes. It is recognized that the overall observing enterprise must engage the scientific, business, public, and government communities from initial conception through to societal benefits. Priorities must be set among interested and committed partners to decide what elements comprise the system and what elements are required to augment the system. There is a natural, generic sequence of activities:

1. Development of an observational/analysis technique within the research and/or operational communities.
2. Community acceptance of the methodology gained through pilot projects demonstrating the utility of the methods and data.
3. Pre-operational use of the methods and data by researchers, application groups, and other end users, with particular emphasis on ensuring compatibility with legacy systems.
4. Incorporation of the methods and data into an operational framework for sustained use in support of societal objectives.

The observing system behind the skillful forecasting of El Niño events has gone through a process like this, for example. [It has been learned that step (3) and the movement from (3) to (4) are difficult.]

The recommendations presented are in four categories:

1. Infrastructure for integrated data and information management,
2. Open ocean observations,
3. Coastal ocean observations, and
4. Implementation.

It is likely that the greatest benefits from an integrated ocean observing system will be realized through the development of an effective data and information management methodology.

Infrastructure Recommendations

These Infrastructure recommendations are based on the experiences of the research and operational communities in the development of effective approaches for the acquisition, dissemination, and utilization of oceanographic information.

1. Initiate quantitative studies to design networks and on-line data storage/archival systems that mix satellite and in situ arrays in a cost-effective manner.
2. Implement a data management system that is complementary to existing systems and attuned to the multiple sources of data and their multiple uses.
3. Implement a national pilot effort to share data from multiple coastal data systems. An example of such a pilot is LABNET of the National Association of Marine Laboratories. This pilot should be a test bed for a larger national system which would include all coastal data.
4. Implement a national virtual ocean data system as intended by NOPP.
5. Agree to a strategy and implement a GIS-like product interface to enable users of the national ocean observing system to have ready access to multiple data sets for multiple purposes.
6. Design and implement a regional test-bed ocean data system that embodies the concepts of recommendations 2-5 above (pilot project); the Gulf of Mexico is an example of such a region.
7. Carry out the Global Ocean Data Assimilation Experiment, a multi-year, global pilot project to assimilate in situ and satellite physical data with the following purposes, among others:
   - To demonstrate feasibility of a global observing system,
   - To develop optimal observing strategies, and
   - To provide data for initialization of climate models, boundary conditions for coastal zone models, and improved ocean descriptions for operational forecasting by the Navy and National Weather Service.

The assimilation of data and the continued improvement of numerical models for transforming measurements into useful products are particularly important.

Open Ocean Recommendations

The immediate benefits of an increased effort in open ocean observations accrue to the objectives involving climate variability, national security, and living marine resources; the immediate benefits of an increased effort in coastal ocean observations accrue to the objectives involving marine operations, healthy ecosystems, natural hazards, and public health. The recommendations are not mapped directly into each of these seven societal objectives because of the overriding issue of integration: each data set is potentially useful for more than one objective. A primary goal of this integrated, sustained, national ocean observing system is to realize this potential.

The following Open Ocean recommendations are based on the comprehensive analysis of the Ocean Observation System Development Panel, thoroughly endorsed by the relevant science and user communities, and on Federal agency requirements. High priority is placed on the development of technologies that provide the means for needed measurements in both open and coastal ocean waters and that disseminate data in a timely manner.

Enhancements for Observations of Surface Fields and Fluxes:

1. Improved Sea Surface Temperature information through:
   - More efficient mix of Volunteer Observing Ships (including commercial fishing vessels carrying observers or vessel monitoring systems), drifting surface buoys, and remote sensing,
   - Improved sensors on Volunteer Observing Ships, and
   - Quality marine meteorological measurements at selected fixed locations.

   Uses: numerical weather and long-range prediction and improvements, seasonal-to-interannual predictions, location of fronts by sport and commercial fishermen, naval operations, improved knowledge of mesoscale circulation for offshore operations, and research.
2. Improved surface wind information through:
   - Sustained satellite surface vector wind observations, and
   - Improved in situ sensors on observing ships and sensors, including quality marine meteorological observations at selected fixed reference sites.

   Uses: improving safety and efficiency of naval and commercial observations, wave forecasts, forecasts of shipboard icing, seasonal-to-interannual predictions, and research.
3. Improved surface ecosystem information through:
   - Sustained ocean-color satellites (now in quasi-operational testing phase), and
   - Improved in situ observations.

   Uses: Estimating global productivity and variability, estimation of carbon fixation, implications for fisheries, improved knowledge of mesoscale circulation by non-renewable energy producers, and research.
4. Improved sea level height information through blend of:
   - Sustained precision sea surface height measurements from satellites, and
   - Sustained and new in situ calibration/validation observations [observing ships, Tropical Atmosphere-Ocean Array, Array for Real-time Geostrophic Oceanography (ARGO)].

   Uses: Estimation of heat transport and storage for monitoring long-term climate variability, monitoring mesoscale circulation for offshore operations, improved surface circulation climatologies for efficient marine transportation, improved wave heights benefit marine and naval operations, and research.
5. Implement more volunteer ships with carbon dioxide observations (pilot project).

   Uses: Reduce uncertainties in air-sea carbon flux needed for climate change monitoring/ evaluation and research.

Enhancements for Upper Ocean Observations:

1. Sustain operational ENSO observing system in the Pacific and maintain support for, as a pilot project, the Pilot Research Array in the Tropical Atlantic (PIRATA).

   Uses: Improve forecasts of seasonal-to-interannual prediction, enhance naval operational nowcasts and forecasts, and research.
2. Continue profiling float deployments through an Array for Real-time Geostrophic Oceanography (ARGO) as a pilot project.

Uses: Enhance naval operational nowcasts and forecasts, improve capability to predict seasonal to decadal climate variability, and research.

Enhancement for Interior Ocean Observations:

1. Obtain global inventories of ocean inventories of temperature, salinity, and carbon through
   - Decadal global surveys.

   Uses: Assess long term climate change (IPCC) and research.

2. Establish/sustain long time series stations to sample the ocean over the full water column at selected locations.
   Uses: To describe transports and changes in selected physical and biogeochemical properties of the ocean (e.g., heat, fresh water, and carbon) on long time scales and to attribute these changes to natural and/or anthropogenic causes.

3. Monitor long-term changes in sea level through blend of
   - Sustained precision altimetry from satellites, and
   - Array of some 30 geocentrically-located, high quality tide gauges.

   Uses: reduce uncertainty in global and regional sea level change and research.

Coastal Ocean Recommendations

The purpose of the coastal component of the observing system is to (1) quantify inputs of energy and materials from land, air, ocean, and human activities and to (2) detect and predict the effects of these inputs on human populations living in the coastal zone, on coastal ecosystems and living marine resources, and on coastal marine operations. These coastal ocean recommendations and how they might be achieved have been reviewed and documented in numerous national workshops and reports.

1. Obtain more accurate estimates of inputs of freshwater, sediments, nutrients, and contaminants to coastal waters on local to regional and national scales through
   - long-term, continuous measurements of flow volume at more sites; and
   - more frequent sampling of key properties, including especially sediment load, nutrient concentration, and selected chemical contaminants.
2. Improve marine meteorological forecasts and coastal circulation models; more timely detection of environmental trends; document the effects of human activities on coastal ecosystems; improve scientific information in support of fisheries management; and assess the efficacy of management actions through
   - the development of an integrated in situ and remote sensing observing system for monitoring and predicting change in selected species of living resources and the quantity and quality of coastal habitats (intertidal, seagrasses, kelp beds, water column, and sediments); and
   - the development of an expanded and enhanced network of moored instruments in inland seas (estuaries, bays, sounds, the Great Lakes) and in the open waters of the EEZ for sustained, synoptic measurements of meteorological (including atmospheric deposition) and oceanographic (physical, chemical, and biological) properties deposition at more locations.

3. Develop a network of coastal index sites (pilot projects).
   Uses: Quantify the causes and consequences of environmental variability in coastal waters and improve predictions of environmental change and human impact in key locations.
4. Implement a comprehensive and integrated program of in situ and remote measurements of water levels, surface waves and currents and timely dissemination of nowcasts and forecasts in all major ports and other coastal waters used for marine operations.
   Uses: Improve the safety and efficiency of marine operations.
5. Document changes in water depth (nearshore shallow water and the deeper waters of the EEZ) and shoreline topography through
   - frequent high resolution topographic shoreline and nearshore bathymetric surveys, and
   - less frequent systematic, high resolution bathymetric surveys of the continental shelf.
6. Integrate distinct sea level observing systems (from measurements to data management) conducted in coastal waters.
7. Establish a coastal data and information management system that leverages existing National Data Center capabilities and which can accommodate the anticipated high volume of coastal ocean data observations.

Implementation Recommendations

These Implementation recommendations are based on lessons learned in the development and deployment of ocean instrumentation and the expertise resident in the various academic, government, and private sector communities.

1. Mechanisms must be set in place to ensure that needed observing elements that have been developed through the pilot stage can be transitioned without loss of measurement continuity through pre-operational to operational phases.
2. Long-term financial support is required to sustain long-term observations.
3. Appropriate guidance and oversight must be set in place to assure recommendations 1 and 2.
4. The observing system must include ongoing strategic planning to set evolving requirements for the system based on evolving user needs, evaluate research and technical developments for potential improvements, recommend needed technical developments, and examine strategic sampling tradeoffs. The system must adequately address the integrated data archival and management needs of users, both operational and research.
5. A continuing review process with annual reports to Congress is recommended.
6. Resources (human and financial) must be available for rapid tactical evaluation of the observing system. The emphasis must be on ensuring that quality-controlled data and products are flowing at the requisite rates.
7. An effective, integrated observing system requires a partnership between the federal agencies with responsibility for the ocean, academic institutions with technical and scientific expertise, and the private sector with socioeconomic requirements, environmental concerns, and resources. The National Ocean Partnership Program (NOPP) is an example of a partnership formed for similar motivations.

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Outline

Prologue

Congressional Request to the National Ocean Research Leadership Council

In August 1998, Congressmen Curt Weldon (R-PA) and James Saxton (R-NJ), Chairs of the Subcommittee on Military Research and Development and the Subcommittee on Fisheries Conservation, Wildlife, and Oceans, respectively, sent a letter to John Dalton, the Secretary of the Navy, and D. James Baker, Undersecretary of Commerce for Oceans and Atmosphere, in their capacity as Chair and Vice Chair, respectively, of the National Ocean Research Leadership Council (NORLC) of the National Oceanographic Partnership Program (NOPP). These letters requested the NORLC to "propose a plan to achieve a truly integrated ocean observing system."

The National Oceanographic Partnership Program

The NORLC is the governing body for NOPP which was established by Public Law 104-201, the FY 1997 National Defense Authorization Act. The Secretary of the Navy is charged in Subtitle E of title II, Division A of this law to establish NOPP:

(1) to promote the national goals of assuring national security, advancing economic development, protecting quality of life, and strengthening science education and communication through improved knowledge of the ocean; and

(2) to coordinate and strengthen oceanographic efforts in support of those goals by (a) identifying and carrying out partnerships among Federal agencies, academia, industry, and other members of the oceanographic scientific community in the areas of data, resources, education, and communication; and (b) reporting annually to Congress on the Program.

The NORLC consists of the heads of twelve federal agencies that are involved in funding ocean research or developing ocean research policy; it is chaired by the Secretary of the Navy. The Vice Chair is the Undersecretary of Commerce for Oceans and Atmosphere (and Administrator of the National Oceanic and Atmospheric Administration). The NORLC has the responsibility to prescribe NOPP policies and implementing procedures including selection of projects, allocation of funds, establishment of a Program Office and an Ocean Research Advisory Panel, and reporting the activities of the Program annually to the Congress. The work of the NORLC is implemented by the Interagency Working Group whose membership reflects that of the NORLC; the Chair is from the Office of Naval Research and the Vice Chair is from NOAA. The NORLC is advised by the Ocean Research Advisory Panel (ORAP), a group of non-federal experts in ocean matters, whose members represent the National Academy of Sciences, academic oceanographic research institutions, ocean policy, state governments, and others. The daily business of NOPP is coordinated by a Program Office, contracted to the Consortium for Oceanographic Research and Education (CORE).

The NOPP Response

Dr. Baker, on behalf of the National Oceanic and Atmospheric Administration (NOAA) agreed to take the lead on behalf of the NORLC to prepare a plan in response to this request. It was agreed that an initial document indicating the way toward a U.S. plan for an integrated, sustained ocean observing system would be submitted to Congress by 19 February 1999. This document has been developed by a task team chaired by Worth Nowlin, Texas A&M University, the chair of the Steering Committee for the international Global Ocean Observing System (GOOS), and co-chaired by Thomas Malone, University of Maryland. The team consisted of both federal and non-federal scientists who have familiarity with related efforts already underway. Advice was obtained from the U.S. GOOS Steering Committee, co-chaired by Nowlin and Malone. The document was reviewed by the NOPP Interagency Working Group and the ORAP and approved by the NORLC.

The Legal and International Basis for a Sustained Ocean Observing System

A number of U.S. legislative mandates explicitly or implicitly require routine ocean observations. The Clean Water Act and its amendments require EPA to restore and maintain the chemical, physical, and biological integrity of the Nation's waters. The Marine Protection, Research, and Sanctuaries Act, Title V, requires EPA and NOAA to administer a national coastal water quality monitoring program. The Coastal Zone Management Act of 1972 created the National Estuarine Research Reserves System that includes monitoring the status and trends in coastal ecosystem health. Data on marine ecosystems are required for effective enforcement of the Endangered Species Act of 1973 and the Marine Mammal Protection Act of 1972. Many other relevant laws exist.

The agreements which provide an international basis to permit the collection of data by the Global Ocean, Climate, and Terrestrial Observing Systems include: the International Convention for the Safety of Life at Sea; the Framework Convention on Climate Change; the Convention on Biodiversity; Agenda 21, the Program of Action for Sustainable Development (agreed at the United Nations Conference on Environment and Development in Rio de Janeiro, Brazil in 1992); the Global Plan of Action for the Protection of the Marine Environment from Land-Based Activities; the Convention on the Prevention of Maritime Pollution by Dumping of Wastes and Other Matter (London Dumping Convention); the United Nations Convention on the Law of the Sea (UNCLOS); and the Agreement on the Implementation of the Provisions of UNCLOS relating to the Conservation of Straddling Fish Stocks and Highly Migratory Fish Stocks. In many cases the data and products from these observing systems are needed by governments to meet their obligations under these Conventions. Special national needs may also be met in part by the results of these systems, such as the informational needs of the U.S. Committee for the Environment and Natural Resources (CENR).

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1. Introduction (Why?)

It has been long recognized that the oceans critically affect human endeavors. Winds, waves, ice, ocean currents, and the hurricanes and typhoons that develop at sea have always affected cargo, fishing, and military ships at sea. Primitive ocean observations systems were initiated centuries ago to measure and try to predict these phenomena.

As uses of the ocean and coastal waters increase, evidence for widespread impacts of these activities on land, the oceans, and the atmosphere is steadily mounting. These interrelated earth systems have been strongly affected by the direct and indirect consequences of human population growth, industrialization, and demand for natural resources. It is increasingly evident that changes in the environment need to be monitored; that effective action must be taken to mitigate damage based on these measurements; and that future changes to the environment be anticipated.

A sustained observation program to detect, track, and predict changes in physical and biological systems and their effects is needed to measure the impacts of humans on the ocean as well as the impact of the ocean on human endeavors. The ocean, comprising over seventy percent of the surface of the planet, is currently monitored far less effectively and completely than terrestrial systems yet humans depend strongly on the sea as a source of food and for transportation and trade, among many other uses. Further, the ocean strongly affects large-scale weather patterns, as so forcefully demonstrated by the recent El Niño and La Niña events. In order to understand and ultimately predict how the ocean-atmosphere interaction affects weather and climate, and how human activities affect both the physical system and living marine resources, an integrated ocean observing system is needed to monitor the 'state' of the ocean. Just as continuous measurements of weather and climatic conditions are maintained on land, similar sustained measurements of the ocean are required to monitor change and to assist in understanding and predicting its impacts.

It is important to recognize that there are already many U.S. observing systems and monitoring programs in place that serve the needs of many users. These systems provide data that helps mitigate losses to life and property, enhance profits to industry, ensures national security, provide information to mitigate anthropogenic changes to the environment, as well as other positive benefits.

It is equally important to state that these observing elements are not integrated and do not constitute a complete system. They are not as cost effective nor useful as they could be, even at present levels of funding. These elements do not serve the complete needs of users. By formulating and implementing a plan for an integrated national ocean observing system, the U.S. will serve better a much wider array of users with only modest increases in costs relative to the additional benefits.

1.1 Needs

There are seven specific areas for which an integrated U.S. ocean observing system is needed: (1) detecting and forecasting oceanic components of climate variability; (2) facilitating safe and efficient marine operations; (3) ensuring national security; (4) managing living resources for sustainable use; (5) preserving and restoring healthy marine ecosystems; (6) mitigating natural hazards; and (7) ensuring public health. Major cross-cutting objectives are strengthening education and improving knowledge.

1.1.1 Detecting and forecasting oceanic components of climate variability

The climate system of Earth has experienced natural variability ranging from the warmth of the Cretaceous to the cold of the ice ages. However, humans have not been just passive spectators of climate variability. Human activities increasingly are recognized as a likely source of profound influence on the nature, timing, and extent of climate change. Through such activities as worldwide burning of fossil fuels and increasing gaseous emissions from agricultural practices, humans have become active participants in changing climate.

As population increases, predictions of climate variations become feasible, and evidence of human-induced climate change increases, policy makers around the world seek information to guide them in their decisions regarding vital issues of economic and social well-being related to climate. The Second World Climate Conference held in 1990 in Geneva recognized the need for a systematic approach to be taken to obtain observations critically needed to answer significant questions about climate change and climate variability. The recommendation from the Conference called for the urgent establishment of a Global Climate Observing System to meet the needs for climate system monitoring, for climate change detection, for climate modeling and prediction, and to provide information for national economic development. The IPCC assessments and the FCCC Conferences of the Parties have drawn heavily on available observations, the underlying science and modeling of climate, its forcing and of the impacts of change in order to reach a consensus on the control of greenhouse gas emissions. Most recently the Fourth Conference of the Parties urged "Parties to undertake programmes of systematic observation including the preparation of specific national plans [and] to actively support national oceanographic observing systems to ensure that the elements…are implemented." (UNFCCC, 1998)

The impact of climate on food production, water resources and sea level and the implications for sustainable development are discussed at length in Houghton et al. (1996) and references therein. The significance of climate in the spread of infectious disease is becoming well documented. Climate also affects life and health indirectly through its effects on supplies of fresh water and food, and on sanitation and housing; for instance, famine induced by droughts weakens people making them more susceptible to disease. Dramatic climate changes in marginal areas create large populations of refugees, as in the Sahel, where drought is linked to fluctuations in sea surface temperature in the eastern Atlantic.

The long-term goals for which systematic ocean observations for climate are being planned and implemented are to monitor, understand, and predict climate change. However, there are many other applications of the resulting data with significant societal benefit. In coastal waters, these observations meet needs of managing living resources, preserving healthy ecosystems, aiding marine operations and others, as well as putting climate changes in perspective for the coastal regions. They also provide a baseline that will enable local observation systems of higher resolution to meet national objectives. Surface ocean data from the ocean observing system for climate will be assimilated into weather prediction models and improve weather forecasts. Thus, the cost and complexity and scale of observations for climate need not be justified only by their benefits to climate monitoring, detection, and prediction; the same observations and many resulting products will produce other benefits in the shorter term.

1.1.2 Facilitating safe and efficient marine operations

Marine meteorological and oceanographic observations and products are needed for many uses, including shipping, coastal and offshore engineering, naval architecture, vessel traffic services, offshore exploration for and production of non-renewal natural resources, prediction of the fate of spills, and recreation.

The needs for marine meteorological and oceanographic services have been examined within the context of the Global Ocean Observing System. The report GOOS 1998 (IOC, 1998a) states that the majority of the required services already are provided by the meteorological services in the public and private sectors. However, there are several areas where an enhanced observing system would add value, in the form of more comprehensive or higher quality services. Suggested enhancements include: (1) international infrastructure for the capture, exchange, and processing of non-meteorological data to support real-time services with international standards and quality assurance; (2) integrated investment in end-to-end observing system elements; (3) enhanced measurements in data sparse regions such as tropical and high latitudes; (4) 'open-ocean' forcing conditions to extend the predictability of storm surge forecasts; and especially (5) more reliable bathymetry.

1.1.3 Ensuring National security

The U.S. has a long tradition of "forward naval presence" in trouble spots around the world to enhance regional stability and global security. To support this national requirement for global reach, the Navy was an early leader in federal efforts to establish worldwide ocean observations and research. While the Navy is continuing a broad-based effort to release much of its data for public use, it still holds—and continues to collect—some of the most comprehensive ocean data sets in the world. Today's high-tech military systems require increasingly sophisticated and timely inputs of ocean data to ensure safety of the fleet, optimize performance and precision, and avoid damage to non-military targets. A robust ocean observation system is vital to the success of naval operations. Understanding the oceans continues to be fundamental to our national security, as well as to global economic and environmental well being.

The U.S. Navy needs analysis and prediction of the traditional suite of ocean/atmosphere parameters that are needed by all sea-going activities, such as winds, waves, visibility, currents, bathymetry, sea ice and sea level. In addition, due to the nature of the Navy's mission, information is required on the temperature and salinity variations at the surface and throughout the water column, as well as ambient (or background) noise and bottom properties in shallow-water areas. The Navy's observation systems have insufficient information (especially real-time) about most coastal zones, suggesting this is a priority region for an ocean observing system to address.

A growing concern is the preservation of the ocean environment. Navy ships and operations are already directed to be aware and take care, and work with an increasing list of specific regulations. An example is the mitigation of ship operations off the north Florida-south Georgia coasts during right whale calving season An integrated ocean observing system for the nation must provide the hard facts and science base for informed decisions on environmental concerns, in our national waters and on the high seas.

Improved data communication and dissemination, integrated data management systems, and technology developments in remote sensing, miniaturized sensors and autonomous systems are additional key areas of national security interest.

1.1.4 Managing living resources for sustainable use

The goal is to provide useful information on changes in the state of living marine resources and ecosystems, and predictions as feasible, on an operational basis. "The users of this information include international, regional, and national regulatory agencies responsible for managing the state of the marine environment, wildlife, fisheries shell fisheries, and aquaculture; non-governmental environmental and wildlife organizations; managers of marine parks and wildlife reserves; sports fishing and tourist organizations; agencies concerned with climate change and its impact on the environment; the research community; and private sector organizations impacting ecosystems" (IOC, 1998b).

Fishing provides protein, employment, industry, recreation, and wealth. The commercial fishing industry provided one of the principal sources of economic growth in our nation's early historical development. The United States is currently the fifth largest fishing nation in the world as measured by the landed weight of the catch. Fishing is a multi-billion dollar U.S. industry with important impacts on many other economic sectors. Per capita consumption of fish products in this country has steadily risen over the last two decades. These observations indicate the importance of the fishing industry to the nation and highlight the need to conserve our living marine resources for the benefit of this and future generations. Recreational fishing is an enormous activity affecting many segments of the economy.

Responsible utilization of our living marine resources is mandated through the Sustainable Fisheries Act of 1996 that re-authorized and extended the Magnuson-Stevens Fishery Management Act of 1986. However, over one third of the fishery resources for which evaluations were available in the most recent national overview were classified as over-utilized (NOAA, 1997). The demands of a growing population, increased emphasis on fish in the diet, and conflicting objectives (e.g., resource conservation vs unconstrained employment in the fishing industry) underlie many of the difficulties experienced in living marine resource management. Scientific advice must be better attended when considering compromises among conservation, economic, and social objectives.

A commitment to sustained observations of all utilized marine living resources is essential for assessment, to setting management objectives, and taking corrective action where needed. This entails continuous documentation of the amount of fish and other resources caught, discarded at sea, and landed as well as the use of independent resource surveys to assess the abundance and biological characteristics of living marine resources. Surveys must be carefully standardized and undertaken independently; this information can not be obtained from the fishing fleet in the course of its normal operations. Changes in oceanic conditions on interannual to decadal and longer time frames have important implications for fundamental levels of productivity in the oceans with direct ramifications for the production of fish and therefore sustainable harvest levels (e.g., under conditions of lower ocean productivity, exploitation rates must be lowered accordingly). To obtain the requisite information needed for management within an ecosystem context, a close integration of information on trends in the abundance of living resources and the environmental and anthropogenic forcing factors, including those of the sea bed, is essential.

1.1.5 Preserving healthy and restoring degraded marine ecosystems

As human populations and activities increase in coastal watersheds, the combined effects of global climate change and human alterations of the environment are expected to be especially pronounced in coastal aquatic ecosystems where inputs of materials and energy from land, sea, air, and people converge. The habitats include not only the water column but also the sea floor. Nutrient and contaminant inputs, the exploitation of living resources, the translocation of nonindigenous species, and the destruction of coastal habitats are causing profound changes in the health of coastal ecosystems nationwide. Indicators of the effects of human activities include: (1) increases in the volume of oxygen-depleted bottom water, harmful algal blooms, fish kills, and the incidence of disease in marine organisms; (2) declines in biodiversity and living marine resources; and (3)"successful" invasions of nonindigenous species.

Episodic meteorological events and longer-term climate change compound the environmental effects of human activities on local to regional scales. As examples, the change in circulation patterns affects the dispersion and the fate of pollutants or the rise in ocean water temperature results in bleaching effects on corals. In addition to their profound effects on the habitats (both the water column and the sediments), biodiversity and productivity of coastal ecosystems, environmental changes such as these are making coastal ecosystems more susceptible to natural hazards, more costly to live in, and of less value to the national economy.

A recent analysis of "ecosystem goods and services" concluded that their global value, in terms of the cost of reproducing them in an artificial biosphere, is on the order of $30 trillion or nearly twice the cumulative global GNP (Constanza et al., 1997). Services provided by coastal aquatic ecosystems (Table 1.1.5-1) were valued at $\$11.4 \times 10^{12}$ with terrestrial ($\$11.1 \times 10^{12}$) and oceanic ($\$7.5 \times 10^{12}$) ecosystems accounting for the rest. Although such analyses of ecosystem services and current predictions of climate change and its effects are controversial, they underscore the importance and urgency of achieving a more holistic, predictive understanding of the responses of coastal ecosystems to inputs from terrestrial, atmospheric, oceanic, and human sources.

Table 1.1.5-1. Ecosystem services provided by coastal aquatic ecosystems in rank order of estimated value (adapted from Constanza et al., 1997).

Rank	Ecosystem Functions	Examples
1	Nutrient storage & processing	Nitrogen fixation, nutrient cycles
2	Removal, breakdown of excess nutrients & contaminants	Pollution control, detoxification
3	Buffer impact of climatic disturbances	Storm protection, flood control, drought recovery
4	None	Boating, sport fishing, swimming, etc.
5	Portion of primary production extractable as food	Fish harvest
6	Habitat, biodiversity	Nurseries, resting stages, migratory species
7	None	Aesthetic, artistic, spiritual, research
8	Trophic dynamics, biodiversity	Keystone predator, pest control
9	Portion of primary production extractable as raw materials	Lumber & fuel
10	Chemical composition of the atmosphere	CO_2, O_3, SO_x

1.1.6 Mitigating natural hazards

Natural hazards are extremes of natural occurrences with potentially devastating effects, often human injury or death. They range from short-term storms with localized impact to climate variations with long reaching impacts. Hazards from climate variations (such as drought) can affect the agricultural production in the heartland of the country, water supplies, or snow removal efforts in mountain and northern areas, and thus can have major effects on the availability and price of food and manufactured goods. Natural hazards that more often come to mind are the short-term events that have catastrophic effects. Gales and other short-term marine events not only slow shipping and occasionally sink vessels, but they are often responsible for damage to equipment and cargo. A single recent storm in the North Pacific was responsible for over $100 million damage to and loss of containers on four vessels. Hurricanes in the southeast have destroyed buildings with high winds, flooded communities with storm surges and heavy rains, and sunk vessels from heavy seas. In addition to direct losses, the uncertainty of the path these storms will take causes major disruptions through wide spread evacuation. In the northern oceans, ice is a very common hazard. In addition to the danger of collisions with floating icebergs, ice forming on vessels can cause capsizing. Perhaps the least recognized natural hazards are those that occur out of sight at the sea floor. These range from shifting shoals that threaten to close ports and ground vessels to shallow gas and unstable sea floor sediments that can rupture pipelines and ocean cables and claim bottom mounted gas and oil drilling and production equipment. The cost of these events in both money and lives lost can reach staggering levels.

Because natural hazards are beyond man's ability to control, mitigating their effects requires accurately predicting when and where they will occur and how severe their effects might be. Improved sea level and seismic observations will help accurately predict tsunamis. Climate and weather related measurements and models need to be improved to more accurately predict the location and severity of hazardous events. By narrowing the area where potentially catastrophic effects might be expected, preparation efforts could be more focused and evacuations could be conducted on a more limited scale with corresponding reductions in costs. An intangible savings would be that citizens would be less likely to ignore warnings to evacuate since fewer people would be requested to evacuate areas that realized no impacts. Additionally, understanding the risk faced by coastal areas to coastal erosion, flooding, and storm surges can help coastal managers plan where to locate and how to protect coastal property. Currently, the coastal property at risk is valued at more than $2 trillion (NRC, 1997). Observations needed for prediction of sea floor hazards have not been conducted on an ongoing basis and are currently very sporadic. Efforts underway to study gas hydrates as natural hazards and as sources of recoverable energy by the Navy, DOE, MMS, NSF and USGS should add much knowledge to monitoring efforts needed to predict sea floor stability.

1.1.7 Ensuring public health

The public depends on the ocean as a source of safe food and safe recreation. Today, diseases and toxins contaminate many marine waters and the organisms living there.

The 1995 National Shellfish Register of Classified Growing Waters reported that nationally, 6.7 million acres of shellfish-growing waters are harvest limited (NOAA, 1997). For 72 percent (4.9 million acres) of these waters limitation was attributed to water quality. During the 1995-1996 reporting period nineteen States reported that 4509 square miles (2.9 million acres) of estuarine waters (27% of the 15,794 square miles surveyed) violated shellfish harvesting criteria. During the same period, 3839 square miles (2.5 million acres) of estuarine waters (16% of the 24,087 square miles surveyed) violated swimming criteria (EPA, 1998). In 1996, 2193 public advisories restricting the consumption of locally caught fish were in effect and over 2500 beaches in the United States were posted with warnings or closed for at least one day due to bacteriological or other types of contamination (EPA and USDA, 1998).

To help protect public health, we must restore and maintain chemical, physical, and biological integrity of our nation's waters. We need to better understand the fate of pollutants in the waters to assist in designing mitigating measures to protect ecosystem health as well, because that can directly affect public health.

Some water-borne pathogens such as bacteria, virus and protozoa cause human illness that ranges from typhoid and dysentery to minor respiratory and skin diseases through direct contact with the contaminated water or consumption of contaminated seafood.

Shellfish may accumulate biological toxin, toxic chemicals, and pathogens (bacteria and virus) that cause human diseases when ingested. Pathogens also impair swimming uses because pathogenic bacteria and viruses can be transmitted by contact with contaminated water.

A recent study conducted by Harvard Medical School scientists found that human gastrointestinal and neurological diseases associated with Harmful Algal Blooms (HABs), bacteria and virus increased during the 1980s and again during the 1990s. Beach and shellfish closures have become increasingly common (Epstein et al., 1998).

Many pathogens and toxins in the marine environment are generated and/or transported by anthropogenic activities. Without proper controls, these problems will intensify as human population increases; in turn, the costs for mitigation will increase. Understanding the physical as well as biological processes in the ocean and the sea floor will assist in assessing the fate of toxins and pathogens and optimizing the design of mitigating measures which in turn will reduce the cost for implementing mitigating measures.

1.2 The economic basis for the system

Forecasts of climate, weather, coastal, and marine conditions create economic value or benefits when producers and consumers can use them to improve the outcome of their economic activities and decisions. As an example, agriculture producers use temperature and precipitation forecasts with lead times of six months to a year to make better decisions on which crops and varieties to plant and which fertilizers to apply. Decisions on how much grain to store can depend on forecasts of the next season's production. Accurate forecasts of coastal ocean conditions can optimize commercial shipping tonnage and ocean routings. Forecasts of natural marine hazards such as harmful algal blooms and red tides can reduce losses in recreation and mitigate human health risks.

Year-to-year variations in climate can have significant economic consequences. For example, the El Niño of 1997-1998 brought a mild winter to the northern mid west and greater than average rainfall to the southwest and west coast of the U.S. As a result, U.S. energy consumers spent $2.2 billion less on oil and natural gas for heating than they do in an average year, and U.S. agriculture production was disrupted at a cost of about $3 billion. Worldwide, effects associated with the ENSO climate phenomenon appear to account for over 20 percent of commodity price movements in recent years.

Recent improvements in world-wide forecasts of seasonal-to-interannual ENSO climate events are generally well known. These improvements result directly from the in situ ENSO observing system in the tropical Pacific Ocean which was developed and tested by the TOGA research program and is now supported operationally by NOAA.

The 1997-1998 El Niño was probably the most widely anticipated ENSO event ever. Forecasters were able to make seasonal outlooks with considerable confidence, especially for the upcoming winter. The magnitude of this event and other weather and climate effects on economic activity, combined with our enhanced ability to forecast these events, has given rise to increased participation in the rapidly growing market for "weather hedges", a form of insurance against losses from weather and climate swings. By some estimates, the market for weather hedges may reach $70-100 billion in a few years (Walsh, 1998).

Economists have estimated the value of improved ENSO forecasts to the U.S. agriculture sector. Assuming that farmers would change crops relative to a normal year if given an El Niño forecast, economists have estimated annual benefits of $240 million to $266 million, nearly one percent of the value of U.S. agriculture (Adams et al., 1995). Were the costs of the TOGA observing system a wise investment, and are further such investments likely to pay off? Annual benefits to U.S. agriculture were compared with the implementation and maintenance costs of the ENSO observing system. Benefit calculations took into account a range in forecast accuracy (from 60 to 80 percent) and a range in farmers' acceptance of the forecasts (from 10 percent in the first year to 95 percent over time). The conclusions are that investments in ENSO observing systems provide an economic return on investment to the U.S. of 13-26 percent annually.

1.3 Rationale for and benefits from a sustained observing system

Arguably the most challenging problem for an ocean observing system is to maintain measurement programs for enough time to capture both episodic variations (e.g., storms) and the long-term variations and cycles required for planning, understanding, and action. Ocean scientists realize that long-period oceanic phenomena are usually more energetic than those with a shorter period, so longer records of sufficient resolution capture the more energetically significant tendencies. However, the degree of difficulty and commitment required to sustain consistent measurements over decades is tremendous. The observations must adapt to technological, institutional, and economic change, as well as changing priorities.

It should come as no surprise that the innovative research environment, which embraces change, is poor at sustaining observing systems. Industry is innovative and sustains systems as needed but is focused on specific objectives, thus not encouraging integration. The observing system envisioned must be both integrating and sustaining while also fostering innovation. Perhaps no single sector of the government-industry-academic partnership is capable of achieving this goal. A combination of interests are needed to ensure that observing systems adapt to new technologies while maintaining continuity in time series of the quantities needed for general use.

Weather analysis/prediction requires sustained observations. Ocean observations are needed for terrestrial weather prediction and for analysis and prediction of sea state and ocean weather. Because the variability of the atmosphere and ocean occurs over a very large range of time scales, observations are needed for very long times if we are to separate natural from anthropogenic variability and begin to make predictions of phenomena affecting the ocean and its users.

El Niño episodes contribute to large-scale temperature departures throughout the world (refer to Figure 1.3-1), with most of the affected regions experiencing abnormally warm conditions during December-February. Some of the most prominent temperature departures include: 1) warmer than normal conditions during December-February across southeastern Asia, southeastern Africa, Japan, southern Alaska and western/central Canada, southeastern Brazil and southeastern Australia; 2) warmer than normal conditions during June-August along the west coast of South America and across southeastern Brazil; and 3) cooler than normal conditions during December-February along the Gulf coast of the United States.

National security is a full-time concern. We cannot put in a place an observing system only for when and where it is needed, because we need to collect background information on the range of variability we can expect to encounter and we do not know in advance from where observations will be needed. In a training sense, the lulls in peace-keeping and war-fighting operations are opportunities for improving skills and tuning systems. The weather services observe and forecast the weather every day, no matter if the day will be good or stormy; they do this so they know how to do it when it is essential, and so the users of the weather information know how to obtain it and use it. Ocean observations are similar, especially for national security and marine weather prediction: it must be done every day, so it is accurate, timely, and useful when it is needed.

Long-term records of fish catch exhibit dramatic changes in response to the effects of human activities and to changes in environmental conditions. For example, the California sardine fishery, immortalized in John Steinbeck's depiction of the Monterey waterfront, expanded rapidly during the early part of this century with landings peaking in the late 1930s (Figure 1.3-2). However, by 1950, the fishery had collapsed. The population has been recovering since 1977, but the fishery has been slowed by conservative management. Interestingly, landings of Japanese sardine also peaked in the late 1930s and had declined by 1950. While overharvesting has been implicated in both declines, it is also evident that a persistent change in the ocean climate occurred from approximately 1930 to the early 1970s. Long term records of the Pacific Decadal Oscillation (PDO) index, which measures changes in sea level pressure and temperature in the North Pacific, show a sharp shift during this period. It has been hypothesized that changes in the position and strength of the Aleutian low (atmospheric) pressure is largely responsible for this regime shift and that this change resulted in fundamental changes in the production characteristics of the North Pacific Basin. This apparent regime shift underlies the basin-scale change in sardine production manifest off the west coast of the U.S. and off Japan.

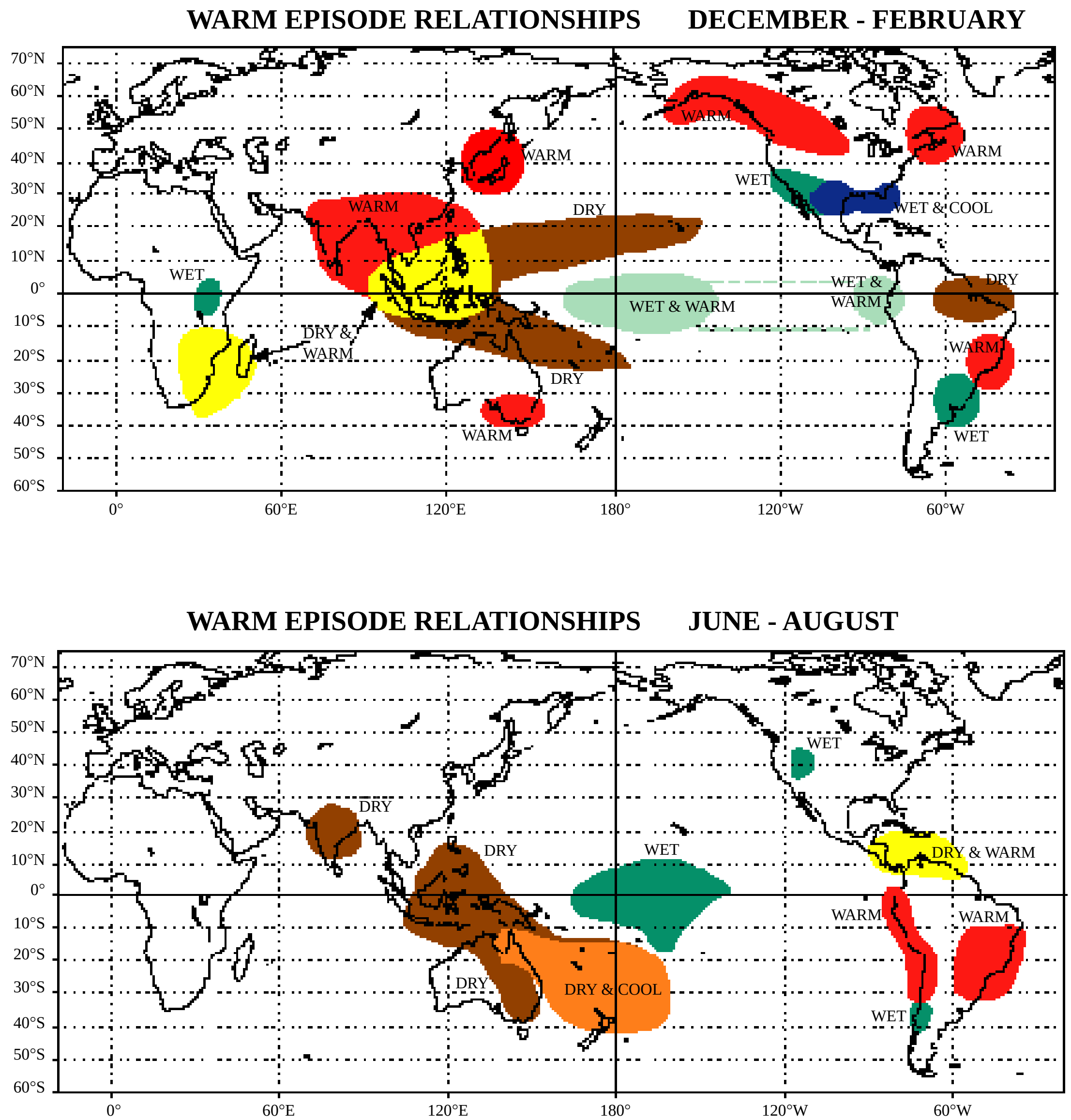

Figure 3.1-1. Climatic changes throughout the world in 1997-1998 due to El Niño.

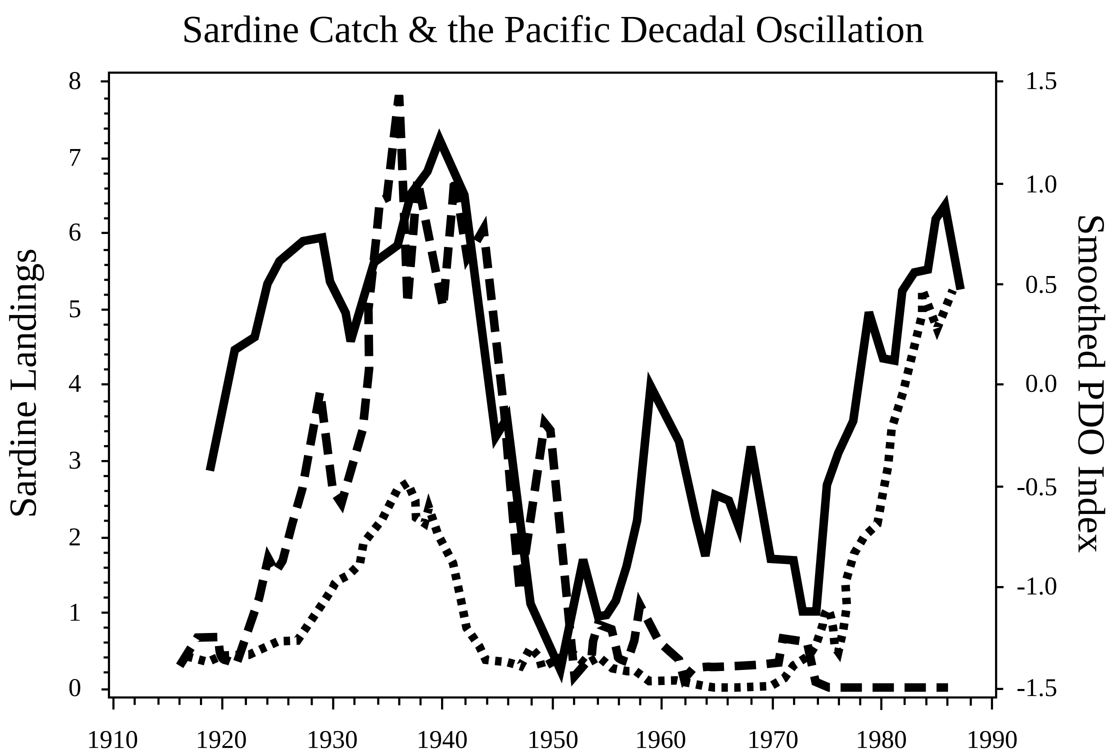

Figure 1.3-2. Landings of California sardine (hundred million t; dashed line), Japanese sardine (million t, dotted line), and the Pacific Decadal Oscillation Index (solid line) during the 20th century.

1.4 Rationale for and benefits from an integrated observing system

The nature and complexity of the broad spectrum of economic and environmental issues faced by modern society has led to a wide array of government-sponsored measurement programs that are not cost-effective on regional to national scales. This calls for an integrated system that is responsive to a broad spectrum of user needs through the combined use of in situ and remote measurements of multidisciplinary environmental variables from shared use platforms. Moreover, secondary users can produce unforeseen added value (e.g., scientific uses of operational data collected for other purposes). The goal is a locally relevant, nationally coordinated, cost effective ocean observing system for multiple, applied uses.

The importance of designing an integrating ocean observing system is documented in many national and international planning reports. In particular, integration will bring together diverse communities by (1) forcing connections between in situ and space-based data, (2) bringing together operational and long-term research programs, (3) encouraging partnerships between the federal, private, and academic sectors, and (4) connecting disciplines and spheres (e.g., ocean, atmosphere, cryosphere, biosphere (The GOOS 1998 (IOC, 1998a)). This bringing together of cultures will greatly enhance the value of individual efforts to the users. Integration will promote cost-effectiveness, elimination of duplication, sustained observations, and responsiveness to user needs.

An integrated system will allow much infrastructure to be used commonly for production of information/products needed for diverse reasons. Common infrastructure needed includes selected positioning systems, measurement systems, communications systems, data quality assessment and control systems, product generation, data archives, modeling and data assimilation capabilities, and technology developments. The commonality of infrastructure is envisioned as a primary mechanism for developing a truly integrated observing system.

2. An Integrated Observing System (How?)

2.1 Characteristics

The U.S. ocean observing system is envisioned as a partnership between U.S. agencies (federal, state, and local), the private sector (profit and non-profit), and academia. A truly integrated ocean observing system requires integration at all levels of effort from within a U.S. partner organization to international collaboration and from data collection to product dissemination. An integrated national plan for a sustained ocean observing system must have the following characteristics (not in priority order):

(1) Coordinated data collection efforts (efforts often in place for different purposes) among U.S. and international agencies to minimize duplication, reduce costs, and maximize data availability.

(2) A balance of remote and in situ observing technologies. Mix and match the strengths and weaknesses of remote and in situ observing systems to design cost-effective and efficient approaches to data collection.

(3) Development of an integrated information management plan to ensure continuous data-streams, timely delivery of data, and adequate quality control.

(4) The ability to meet the requirements of multiple users by integrating observations collected for different purposes.

(5) Adaptability to new and changing user requirements for ocean data and products.

(6) Development of criteria for prioritization of existing and proposed observing systems.

More specifically, the elements of this system must meet certain criteria that in effect constitute a definition of what is meant by operational for this observing system:

<u>Relevant to needs</u>. Measurements should be in response to needs for information, including products derived from models.

<u>Long term</u>. Measurements, once begun, should continue into the foreseeable future. Continuity in the observed quantity is sought rather than in the method, and it is anticipated that more effective methods will become available with time.

Systematic. Measurements should be made in a rational fashion, with spatial and temporal sampling tuned to address the issues. Further, measurements should be made with the precision, accuracy, and care in calibration required to provide continuity in the quality of data in space and time even though different methodologies may be used.

Subject to continuing examination. Trade-offs must be subjected to evaluation on a continuing basis to take advantage of new knowledge and technology.

Because of the scope and intended longevity of the observing system, it is realized that there are further practical constraints on the measurements:

Cost effective. To maximize the number of required observations using the available resources (financial and manpower), the observational methods used in the observing system must be economical and efficient.

Timely. The ability for users to access and retrieve observations with sufficient timeliness to meet their needs. Some requirements are for real-time data delivery. In other cases substantial quality control will require lapsed time between measurement and data delivery.

Routine. The observation tasks should be carried out by trained staff, responsible for acquisition and quality control of data and the dissemination of products. Thus for some variables, the collection of observations and related work may be integrated into agencies capable of making a long-term commitment; for other variables, the desired quality of routine observations may be best achieved by providing long-term support to ensure the quality and continuity of the measurements.

2.2 Open ocean and coastal components: an approach

The benefits of an ocean observing system can be, and have been, discussed as related to seven areas of need. However, the implementation and maintenance of a truly integrated national observing system can not be effected in seven parts.

Initially at least, the system will be composed of an open ocean subsystem and a subsystem for coastal waters, supplemented by the required common infrastructure. Here coastal waters include the U.S. EEZ and estuaries, bays, sounds, and the Great Lakes. The open ocean subsystem has been designed principally in response to needs in the areas of defense, climate, and marine commerce, although many of these observations are also needed and used in support of objectives of the coastal subsystem. The coastal subsystem is designed to assist multiple users in assessing and predicting both natural and anthropogenic variations. The U.S. is joined by other nations in collecting the observations needed for the open ocean subsystem. Most of the observations needed for the coastal subsystem are from U.S. coastal waters, but some regions of coastal waters are under the joint jurisdiction of more than one nation (e.g., the Great Lakes or the Gulf of Mexico) and an international approach to developing an observing system is indicated. Moreover, some measurements from coastal areas not contiguous with the U.S. are required, particularly for national security, industry, and resolving the effects of human activities from natural variability. These may be obtained either by sharing data with other nations or by purchasing the needed data.

In contrast to the open ocean where air-sea interactions drive environmental variability and coastal systems provide boundary conditions, coastal waters are in a transition region where ecosystem goods and services are concentrated and inputs of materials and energy from land, sea, air, and people converge. As a consequence of the diverse nature of these external forcings (or stresses), the proximity of the benthic boundary layer to the air-sea interface, and the constraints of coastal geomorphology, the environmental issues that must be addressed by the ocean observing system in coastal waters are complex, local (e.g., a bay or estuary) to regional (e.g., the southern California and middle Atlantic bights) in scale, and globally ubiquitous in scope (Malone, 1998). The challenges of resolving anthropogenic from natural sources of variability and of documenting and forecasting variability and predicting longer term trends are further complicated by the reality that coastal systems exhibit more variability over a broader range of time and space scales than is found in large, oceanic systems (Steele, 1985; Powell, 1989).

At this time there are clear differences between the global and coastal observations that favor this division. These include: the difference in spatial and temporal scales of sampling required; planning for the design of these two observational components is at different stages of development; global observations are generally made within an international framework of cooperation, but coastal observations are likely of local/national concern.

2.3 How will an integrated observing system be achieved?

To achieve the goal of an integrated ocean observing system requires certain key actions. These are grouped into three classes: system design and implementation; optimal use of data; and guidance, oversight, and funding mechanisms. Activities in these three areas must proceed in parallel.

System design and implementation.

(1) Formulate an initial design based on identified user needs.

(2) Establish and utilize criteria (e.g., cost/benefit ratios, operational constraints, etc.) for prioritizing observing systems. These will provide funding sources a mechanism for evaluating present and future networks.

(3) Identify ongoing data collection activities by U.S. agencies and institutions that contribute to the needs.

(4) Identify deficiencies to existing observing components based on user needs.

(5) Propose augmentations to existing subsystems and new subsystems with estimated benefits, costs, and schedules.

(6) Identify new needs and develop new observing system elements to meet changing requirements, technologies, and available resources.

Maximize use of data.

(1) Use integrative approaches (sampling technologies, models, data assimilation, underpinning research) to strengthen the observing subsystems. As an example, quantitative studies are needed to design networks that mix remote and in situ arrays in a cost-effective manner.

(2) Evaluate present data management activities and improve them. It is most likely that the greatest benefits from an integrated ocean observing system will be realized through the development of an effective data management methodology.

Guidance, oversight, and funding mechanisms.

(1) Develop appropriate guidance and oversight mechanisms to enable transition of needed system components to operational status, to ensure the continuity of proven systems that are operating, and to ensure system integration.

(2) Identify innovative mechanisms for funding the system that allow for participation by all U.S. partners (state, federal, and local governments; profit and non-profit elements of the private sector; and academia).

Many elements of a national ocean observing system are in place at the present time. However, the system is neither integrated nor complete as to its ability to meet the needs of all users. The essential strategy is that the U.S. observing system will be built on the existing elements where possible, and the overall plan will be developed based on existing recommendations completed by the larger community, U.S. and international. It is unreasonable to include in the plan new observing system components not yet properly evaluated by users and specialists. For such components, this document indicates the way to complete the design; improvements will be included in future versions of the plan. Although a well-considered design for a specific observational component may not be available at a given time, the component may still be essential to a complete integrated system. When well-considered component designs are available, they will be integrated into the larger plan—perhaps necessitating changes to the previous designs of other components. The design/plan for the system will never be complete/static; evolution and adaptation will be ongoing as needs, knowledge, and technology evolve.

An illustration of what is meant by an integrated system of sustained observations is provided in Figure 2.3-1. This figure shows the trade-off between continuity and integration for some existing and planned ocean observation efforts. "Continuity" is defined as the assurance that the observations will be sustained in perpetuity; an example is the weather-observing network. "Integration" is defined to mean that the observing system (observations and data management) covers a breadth of parameters and serves the needs of multiple users. There is no ocean system that ranks high in both dimensions. The target is for a system that is both highly integrated and sustained. Process experiments, focused narrowly and realized probably only once, are neither. The present data archives, numerical weather prediction (NWP) and in situ sea level measurements are sustained, but very narrow, while the Tropical Atmosphere-Ocean array (TAO) and the Climate Variability (CLIVAR) program are somewhat sustained but also rather narrow in scope. The Louisiana-Texas Shelf Circulation Study (LATEX) and the Global

Ecosystems (GLOBEC) program are coastal and global examples of elements somewhat integrated across disciplines, but with no continuity beyond limited sets of observations.

Pilot programs can be used to approach the objective of being both sustained and integrated. They must be relatively broad in their integration of measurements and objectives and must be continued for periods long enough to establish their efficacy. Three examples of pilots are the Global Ocean Data Assimilation Experiment (GODAE), the Array for Real-Time Geostrophic Oceanography (ARGO) plans as a project to measure upper ocean temperature and salinity together with reference ocean current speeds and intended as a complement to GODAE, and the Long-term Ecosystem Observatory at 15-m depth (LEO-15) that is underway and integrating multiple coastal measurements.

These and additional examples of ongoing or potential pilot projects are given in Appendix 2.

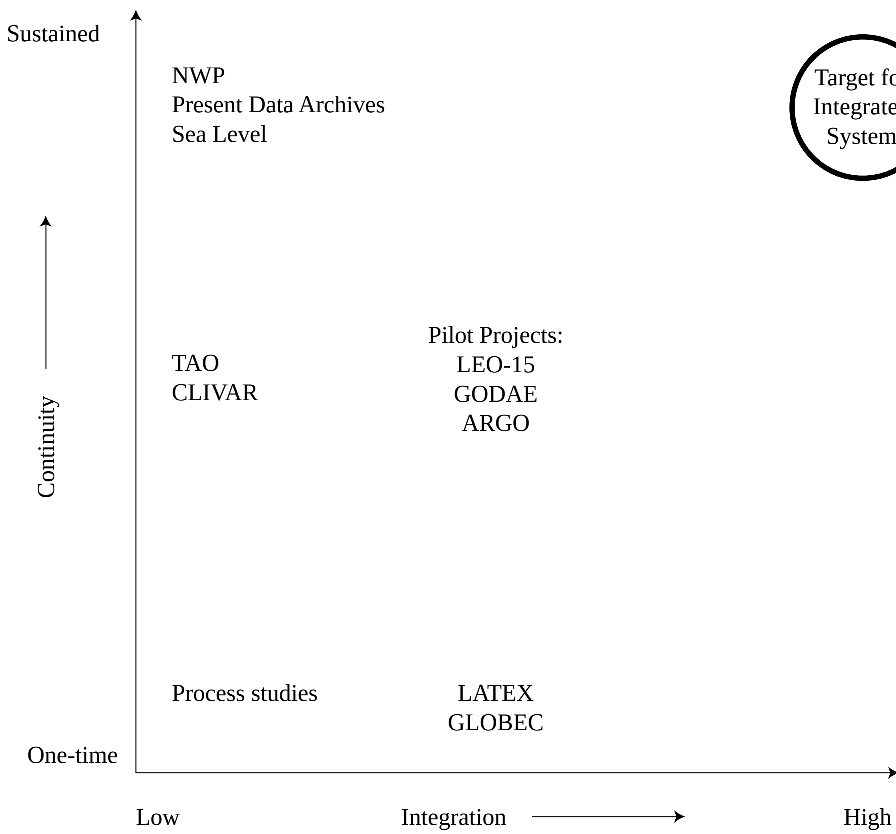

Figure 2.3-1. Relative degree of continuity and integration attributed to example observational project: numerical weather prediction (NWP), Tropical Atmosphere-Ocean (TAO) array, Climate Variability (CLIVAR) program, Louisiana-Texas Shelf Circulation Study (LATEX), Global Ecosystems (GLOBEC) program, Array for Real-time Geostrophic Oceanography (ARGO), Global Ocean Data Assimilation Experiment (GODAE), and the Long-term Ecosystem Observatory at 15-m depth (LEO-15). Note that the objective is to be both integrated and sustained.

3. Design and Status of a U.S. Ocean Observing System

In this section the existing design for the observing system and the status of U.S. implementation of that design are described. In specifying components, the many design studies for sustained ocean observations, carried out and in progress, have been examined and used. Citations to these studies are given, but the rationale contained therein are not repeated.

3.1 Infrastructure

The common infrastructure for the sustained, integrated ocean observing system are those elements providing platform location, data communication, protocols and standards for data collection and quality control, data storage, and data redistribution. More effective methodologies for interpolating, extrapolating, and drawing inferences from measurements should reduce reliance on any one particular observation, and so build confidence in results. Ultimately much of the analysis will be performed by assimilating the observations into numerical ocean models. The objectives of this infrastructure include:

1) To improve and expand effectiveness of shared use platforms and sensors.

2) To improve and expand the data management and communication facilities necessary for routine monitoring, analysis, and prediction of the ocean on required time scales.

3) To improve and expand facilities for processing assembled data sets and providing timely analyses, model interpretations, and model forecasts.

4) To enhance and develop application centers to assist with the interpretation and application of observations and products to users, as examples: improved climatologies (means and variances) of key ocean variables (e.g., temperature, salinity, velocity, carbon, nutrients, and biomass) and the temporal evolution of these variables.

3.1.1 Data management strategy

The operational data flow in the U.S. ocean observing system is end-to-end, that is, from the observing system to the end users, and concurrently into distributed archives for retrospective analysis. The data management strategy recognizes the multiplicity of data sources and data types, the multiplicity of users and their varying needs, and the overarching concerns of quality assurance, timeliness, and accessibility of data and data products.

Data management plans already exist for most of the specific aspects of the U.S. ocean observing system. The goal of this plan for a national integrated ocean observing system is to describe the integration and melding of the existing plans, and define the missing pieces. The approach is to summarize existing plans and deficiencies, and to provide an initial strategy for how the gaps will be filled.

3.1.1.1 Existing data management plans relevant to the U.S. ocean observing system

The magnitude of the challenge of developing an integrated data management strategy is indicated by the diversity of currently functioning national and international data management systems. These include at least 13 major data management systems run by the U.S. and UNESCO; see Appendix 3 for further information on them. The full list of relevant data management documents, approaches, and web sites is quite long, but there are clear similarities among them. The common objective is to move data from its observational point to an archive and/or an end user, while assuring the usefulness and quality of the data, its timeliness, and its accessibility. Exactly how this is done varies from system to system, and tends to be specialized for the particular data and user community.

Differences in the methods of controlling the quality of measurement fields may be related to differences in scale and the opportunity for in situ observations (e.g., global sea surface temperature fields versus coastal water levels). Differences also exist because of different needs of the user communities. For example, the climate research community needs very high quality data without urgency, whereas the operational forecasting community needs data immediately following its measurement, and is willing to sacrifice some quality to obtain timeliness. If both of these communities require the same observed data (for example, sea surface temperature), the data management system must be compliant to both constraints: quality and timeliness. The commonality is that both communities must address the tradeoffs, and the data system must allow both communities to function.

Because of the multiple users with different time constraints for their products, data can be used multiple times. Often this involves multiple levels of data quality control, leading to ever more useful data sets.

In summary, data management systems already exist for most types of data that will be collected in the U.S. ocean observing system, although some of the systems are not well tuned to the actual needs of the user communities and few of the systems are readily able to exchange data with each other. Additionally, an end user may need to acquire data from a large number of the different data management systems, hence has to wrestle with varying formats and access requirements. Thus, the fundamental requirements are:

- an integration of existing systems;
- more attention to the needs of the end users (especially timeliness);
- responsive and sufficient quality control;
- provision of appropriate metadata;
- free and open access.

Many existing documents and recommendations aim directly at the issues of the final four bullets; the path on which to proceed is clear. Needed is action with a foremost intent on integrating the existing data systems.

3.1.1.2 Interface systems and the role of standards

In the past we have had data systems designed primarily for one suite of data and one group of users. This is illustrated in Figure 3.1-1. Essentially these systems were independent each with its own formats and input standards. Multiple use was not often expected.

Today, many, if not most, users need multiple kinds of data. However, data systems with their individual and often distinct protocols still are designed largely for particular types/suites of data. Therefore users must contend with a multiplicity of formats and standards as illustrated in Figure 3.1-2.

Consequently, the data strategy of the U.S. ocean observing system is to define two standard interface formats and one metadata format (Format refers to the digital arrangement of the information; metadata refers to the information that must accompany data to render it useful, e.g., instrumental and calibration information). The future is illustrated by Figure 3.1-3.

1 The exchange formats are those that take data from existing data systems and put them into usable formats for application purposes. A working prototype is the Distributed Oceanographic Data System (DODS) formulated by the University of Rhode Island and the Massachusetts institute of Technology. As an example, a system such as DODS could evolve to be the "many-to-one" translator so that the large number of existing data sets and systems is irrelevant to the application centers and end users. In this architecture, major archives such as the National Oceanographic Data Center and the Naval Oceanographic Office become providers of data for retrospective purposes.
2 The product formats are those that allow data from existing application centers to be overlaid, combined, amalgamated, jointly displayed, etc. Today's geographical information systems are the prototype.

3 The metadata formats are those that specify data source, quality, processing, units, etc. The prototype for the metadata formats is that derived from the Federal Geographic Data Committee (FGDC) and used in the Master Environmental Library of the Department of Defense. The intention is to be compliant with the FGDC standards by using an appropriate subset.

In addition, a Data Service Unit is required to respond to inquiries, manage "configuration change", and coordinate evolution of the formats.

The value of having standard interface formats and data/interchange protocols cannot be understated. The National Association of Marine Laboratories (NAML) has demonstrated this value in its experimental LABNET initiative (http://www.mbl.edu/html/NAML/brochure/LABNET.brochure.html). This initiative, in its early stages, is experimenting with the integration of disparate data from multiple research sites to support products useful in both research, management and educational outreach. This initiative, along with other emerging grassroots efforts, should be examined in order to define an approach that would be applicable at a National level.

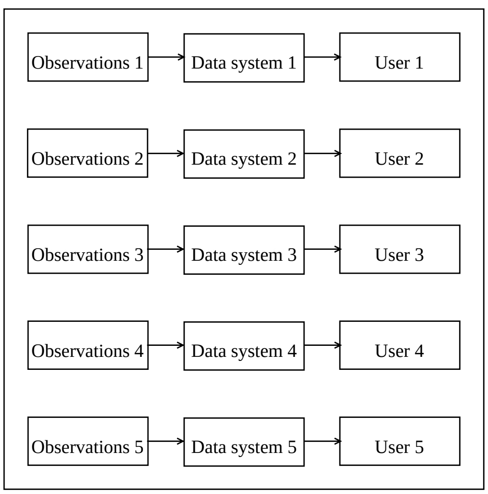

Figure 3.1-1. **Yesterday:** Unintegrated, separate data systems, designed primarily to get one kind of data to one kind of user. This works well if each user is satisfied by one (or few) kinds of data.

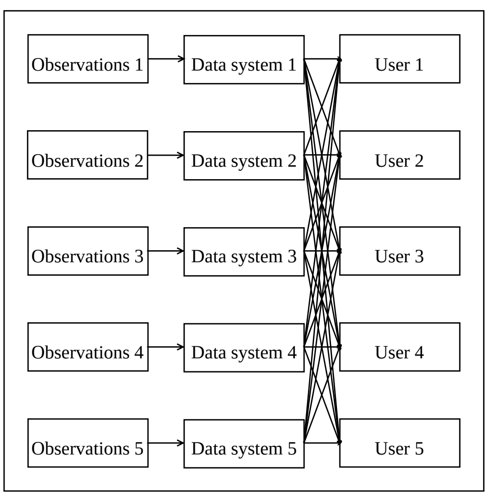

Figure 3.1-2. **Today:** Most users now need multiple kinds of data, so must fight multiple systems with varying formats and standards. They must work out data access arrangements with all the possible data systems. Every new kind of data requires all users to work out new arrangements.

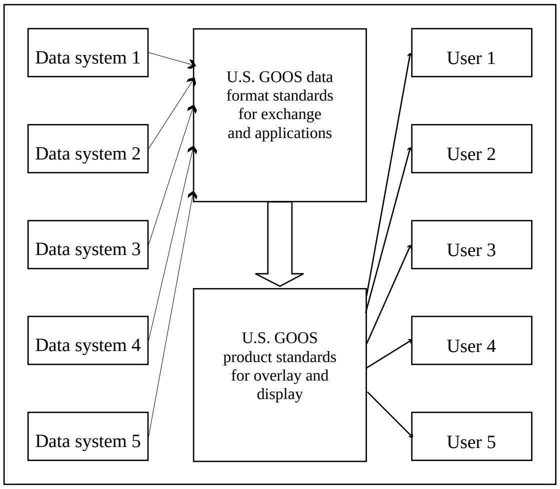

Figure 3.1-3. **Tomorrow:** Integrated, coordinated data systems, designed primarily to allow users to exploit multiple data sets. The Data Standards effort serves to get at the data from all the disparate data systems. The Product Standards effort provides data to all the disparate users. The coordination between the Data and Product efforts is internal to an integrated ocean observing system, and transparent to the data providers and the users. A new kind of data must only be dealt with once, by the Data and Product efforts. In addition to the flow of data to users, all the data sets must flow to national archives, as they mostly do now. Some of the archives are governmental, some are maintained by universities, and some will need to be maintained as part of this integrated observing system. All of the archives represent potential data flow into the Data and Products activity, because blending retrospective data into real-time observations is required by many end-users.

The Global Ocean Data Assimilation Experiment is an example of a pilot project which could also contribute directly to the desired directions by integrating available in situ and satellite observations globally for multiple users and products.

3.1.2 Recommended actions

The actions required to implement a data management system for a national integrated ocean observation system are listed below. The overriding principle is to get started in ways that are expandable, and to learn by doing. It is unlikely that a perfect system can be designed without the experience of smaller, more prototype systems.

Steps to implement the data infrastructure:

1. Convene a multi-sector (government, industry, academia) series of workshops to agree to the architecture for a data management system that is supplementary to existing systems and tuned to the multiple sources of data, multiple users problem; this will include specific attention to the development and implementation of data standards and exchange protocols. As an example, the prototype could be a combination of DODS, LABNET, Master Environmental Library, the hub-node concept described in Powell (1998), and the objectives of a distributed data system in which individuals and institutions serve our their data in accordance with community conventions (called a National Virtual Ocean Data System; CORE, 1998).
2. As an interim measure until Step 1 is complete, call for proposals to implement pilots, making sure they are expandable as a part of an overall system.
3. As a second interim measure until Step 1 is complete, call for proposals to implement a national virtual ocean data system that blends the existing archives into a distributed system that provides easy user access to multiple data sets.
4. In parallel with Step 1, convene a multi-sector (government, industry, academia) series of workshops to examine the capability and deficiencies of current GIS systems to act as a product-interface for the users of a national integrated ocean observing system. Define specific efforts required to enable one or more GIS systems to meet the initial needs.
5. As a cross-cutting objective and action, initiate as soon as practical a strawman data management system for a limited region (one example being the Gulf of Mexico) that interfaces with existing National Data Centers and has the elements of multiple data sets, multiple users, and blending of archival and real-time information. The goal is to have a test-bed, learning system to build from, rather than trying to design the final system at the outset.
6. Carry out a U.S. component of the Global Ocean Data Assimilation Experiment, a multi-year, global pilot project to assimilate in situ and satellite physical data with the following purposes, among others:
   - To demonstrate feasibility of a global observing system,
   - To estimate the state of the ocean at regular intervals and thus changes,
   - To develop optimal observing strategies, and
   - To provide data for initialization of climate models and boundary conditions coastal zone models.

It is recommended that various integrative approaches be used to strengthen the observing subsystems. As an example, quantitative studies are needed to improve and integrate existing networks and to design new system elements that mix remote and in situ arrays in a cost-effective manner.

The existence of a robust data and information structure for the national sustained ocean observing system will not only make ocean observations more useful for our stated classes of needs, it also will allow better use of data and information for education, fundamental research, and focused research efforts, such as MMS environmental research in gas and oil operation areas.

3.2 The open ocean observations

On behalf of both GOOS and GCOS, the Ocean Observing System Development Panel (OOSDP, 1995) selected a set of goals and objectives regarding the ocean and its role in climate which address the key issues regarding monitoring, detecting, understanding, and predicting climate variability and change. The four major goals deal with needs for: (1) information regarding ocean surface fields and air-sea fluxes, (2) information regarding the upper ocean (the region of greatest availability and extending to depths of order 1000 m), and (3) information regarding the interior ocean (below the main thermocline and including the sea floor), and (4) for infrastructure and techniques which will ensure that information obtained is utilized in an efficient way. The objectives were prioritized and an implementation sequence for observing elements recommended. The Ocean Observations Panel for Climate (OOPC), reporting to GOOS, GCOS, and the World Climate Research Program, continues to refine the design for ocean climate observations and has begun to assist with implementation. Many specific improvements have been possible because of new technologies and scientific results.

As a major partner in developing these general goals and objectives, the U.S. has the same objectives for ocean observing system components in support of climate issues and will participate in its implementation and future refinement. The elements of this observing system for climate are included in the open ocean component of the national system described here and the status of their implementation is reviewed. Details may be found in referenced source documents.

The needs for observations to facilitate safe and efficient marine operations were briefly reviewed in Section 1.1.2. The required observing system elements are incorporated into the design and status of the open ocean observing system component described in this section. In addition to services already being provided, priorities to better meet the needs of end users were enunciated by Komen and Smith (1997). (1) For ocean wind and wave forecasting, improve the accuracy of observations of wind speed and direction and their distribution in real-time and improve the quality of medium range forecast winds. (2) For the prediction of tsunamis, make real-time collection of open ocean sea level measurements and improve bathymetry. (3) For storm surge forecasts and warnings the operational services in the North Sea, provided by the UK and the Netherlands, are good role models. Improve measurements of meteorological forcing, bathymetry, and coastal geometry are critical, as well as use of three-dimensional models. (4) For sea ice services, improve discrimination of ice cover at the ice edge where a mixture of open leads and solid ice prevails (Cattle and Allison, 1997) and provide more comprehensive prediction of small icebergs in open water.

National security needs for open ocean observations are open ocean wave, weather, and ice forecasts as well as temperature, salinity, and sound velocity measurements for sonar tracking. A more comprehensive status of Navy observations is found in Appendix 1.

Although the overwhelming majority of fishery production is taken within the coastal waters and Exclusive Economic Zones of maritime nations, important fisheries are found also in open oceanic waters. These fisheries are typically managed under international treaties and scientific assessment of their status is typically conducted through multinational organizations. Particularly important examples of fishery resources in this category are highly migratory species such as tuna in the Eastern Tropical Pacific and in the North Atlantic, swordfish, and salmon harvested on the high seas in the Pacific. Assessment of the status of these resources is essential for effective management, and institutional arrangements are in place to monitor the landings, size and/or age structure, and other biological characteristics of the catch.

The possibility of harvesting other fishery resources of the open ocean has attracted considerable attention. For example, extensive populations of mesopelagic fishes and squids are thought to exist in open oceanic waters. Cost-effective means of harvesting these resources, which occur at relatively low density and at great depth, do not currently exist. Other newly discovered resources in international waters have been subject to recent exploitation (e.g., orange roughy in deep water basins in the North Atlantic). As expanded exploitation of fishery resources in open ocean waters occurs, a more extensive monitoring network must be established to accommodate demands for resource assessment and evaluation.

Following the structure of the ocean observing system for climate, the open ocean component of the integrated U.S. sustained ocean observing system is described in terms of information regarding (1) surface fields and fluxes, (2) the upper ocean, and (3) the interior ocean. This grouping is consistent with differences in time and space scales of pertinent phenomena and processes within the three regions.

In Table 3.2-1 are indicated some user constituencies for data and derived products from these three open ocean areas grouped by the seven needs discussed at various places earlier in this document. Even though the table is not meant to be exhaustive, the multiplicity of users for products derived from most types (e.g., surface fields and fluxes) of observations is clear. Many of these users benefit from products or data acquired primarily for different needs, illustrating the strength of integration.

Easily identified products required from the observing system are listed in Table 3.2-2, again grouped by general class of needs and by region of the open ocean. With this table the multiple uses of products is even clearer. Many additional products could be identified, and surely many unforeseen products will prove to be of great value to users once an integrated system is established.

Table 3.2-1. User constituencies for observations and products from the open ocean component of the observing system.

Needs	Surface fields and fluxes	Upper ocean	Interior ocean
Climate	IPCC National and international policy makers Prediction centers Regional analysis centers Agribusiness Power suppliers Health services Researchers	IPCC National and international policy makers Prediction centers Regional analysis centers Agribusiness Power suppliers Health services Researchers	IPCC National and international policy makers Researchers
Marine Operations	Marine transportation Resource producers, e.g., petroleum Fishing industry Search and rescue operations Oil-spill clean up	Resource producers, e.g., petroleum	Resource producers, e.g., petroleum
National Security	DoD	DoD	DoD
Living Resources	Policy makers Researchers NGOs Ecosystem managers	Policy makers Researchers NGOs Ecosystem managers	Researchers
Healthy Ecosystems		Environmental quality managers Policy makers Researchers	
Natural Hazards	Prediction centers Policy makers Researchers	Prediction centers Policy makers Researchers	Prediction centers Policy makers Researchers
Public Health			

Table 3.2-2. Products from the open ocean component of the observing system. (P) indicates that predictions in addition to analyses are needed.

Needs	Surface fields and fluxes	Upper ocean	Interior ocean
Climate	Daily sea surface temperature maps Surface wind speed and direction (daily) Surface fluxes of heat and fresh water (monthly) Surface salinity (monthly) Air-sea carbon dioxide exchange (monthly or seasonal) Extent, concentrations, volume, and motion of sea ice (monthly) Global productivity	Monthly temperature and salinity distributions Temperature for initial and constraining seasonal-to-interannual (ENSO) models Carbon exchange with interior ocean	Global and regional sea level variation Carbon, heat, and fresh water inventories (decadal) Ocean circulation and transports and changes of physical and biogeo-chemical properties (heat, fresh water, and carbon) on long time scales; attribution to natural or anthropogenic causes
Marine Operations	Daily sea surface temperature maps Marine weather (P) Surface wind speed and direction (P) Tides and surface currents (P) Surface waves (P) Fog (P) Sea ice extent and concentration (P) Iceberg positions (P)	Currents (P)	Currents (P)
National Security	Sea surface temperature maps (P) Marine weather (P) Surface wind speed and direction (P) Tides and surface currents Sea ice extent, concentration, thickness, and motion (P) Gravity (geoid)	Temperature, salinity, and sound velocity (P) Ambient noise	Bottom depth and type (characteristics) Gravity and magnetics
Living Resources	Sea surface temperature maps Global productivity	Highly migratory fish stocks	
Healthy Ecosystems		Time series of selected biota and pollutants	Time series of selected biota and pollutants
Natural Hazards	Storm movements	Sea-level rise	Tsunami warnings
Public Health			

3.2.1. Sea surface fields and air-sea fluxes.

3.2.1.1 Design

Almost all the information needed to determine the ocean's circulation and properties is originally communicated through the air-sea interface, so the estimation of ocean surface fields and air-sea fluxes is a fundamental requirement of the ocean observing system. Sea ice is included because measures of its extent, concentration, and thickness are intimately related to the fluxes of heat and water to and from the ocean. The observing system requirements at the sea surface are:

1) In situ measurements of sea surface temperature that, when combined with satellite measurements, are adequate for defining SST field variability on daily, monthly, seasonal, interannual, and longer time scales. Sea surface salinity and its variability should be measured where it can be determined with sufficient accuracy to produce useful products.

2) Global distributions of the surface flux of momentum (wind stress) on daily, monthly, seasonal, interannual, and decadal time scales.

3) Global distributions of the surface fluxes of heat and fresh water on monthly, seasonal, interannual, and decadal time scales. Additional constraints on these estimates will be provided by estimates from upper ocean budgets.

4) Descriptions of the global distributions of sources and sinks for atmospheric carbon dioxide and the carbon exchanges within the interior of the ocean. Initially, monthly climatologies of the exchanges are required to resolve longer term changes in the presence of strong variability on interannual and shorter time scales.

5) The extent and concentration of sea ice and position and movements of icebergs daily and the volume and motion of sea ice on monthly and longer time scales.

6) Climatologies, nowcasts, and predictions of surface wave fields.

7) Regional and global estimates of productivity for use in living resource assessment and management and in estimating the biological pumps impact on climate variability.

3.2.1.2 Status

In support of required ocean surface fields and air-sea fluxes, the U.S. now has many operational observing components, the majority of those now in place support requirements for routine numerical weather prediction and naval operations. Here the status and future needs are reviewed briefly.

1) Sea surface temperature is obtained as a product of blending global satellite measures of radiation from the sea surface with more accurate point measurements of surface temperature from commercial vessels making voluntary measurements and from dedicated surface drifters. The status is that operational funds are inadequate to sustain the level of drifter and volunteer observing ship observations required. Moreover, funds are needed to upgrade the technique being used on volunteer observing ships from measuring injection water temperature to measuring with hull contact thermistors. Trade-offs should be carried out on the impacts of the mix of samples from volunteer ships and drifting buoys and their spatial distributions.

   Surface salinity estimates now are obtained from profiling floats, surface drifters, and merchant vessels. However, these observational platforms do not yield the required time-space coverage. The potential for estimating surface salinity by satellites globally with sufficient accuracy for climate issues is being investigated by NASA. The in situ techniques could then be used for validation/calibration.

2) Surface wind stress is currently obtained as a by-product of numerical weather prediction which is constrained by observations from merchant, Navy, and Coast Guard vessels. The realism of the resulting fields is not adequate for modeling climate scale variability except in areas where weather prediction results are constrained by high volume of merchant ship traffic (namely the mid-latitudes of the North Atlantic and North Pacific oceans) or where supplemental in situ measurements are made (e.g., in the tropical Pacific as part of the operational ENSO observing system). The requirement is for continuing global measurement of surface wind vectors by broad-swath scatterometers on satellites, and for improved in situ sensors on observing ships and sensors, including quality marine meteorological measurements at selected fixed reference sites.

3) Surface fluxes of heat and freshwater are now obtained principally as the results of numerical weather prediction models, but they are not accurate enough for assessment and study of climate variations. Required for validation of model results and model improvements are measurements from improved in situ sensors on observing ships and quality marine meteorological sensors at selected fixed positions.

4) Sources and sinks to the ocean of atmospheric carbon dioxide are now measured from research ships and platforms. Such measurements are inadequate to establish with needed certainty the global and seasonal distributions. As a pilot project, more volunteer observing ships should be instrumented to make observations.

5) The horizontal distribution of sea ice is regularly monitored and reported by the National Ice Center, operated by jointly Navy, NOAA, and Coast Guard. In regions of heavy shipping, the locations of icebergs and extent of known ice is monitored and reported by the International Ice Patrol in the North Atlantic. These activities should continue. There is the further need to estimate ice thickness, and thus volume, on a continuing basis, but a methodology for routine measurement at reasonable cost does not now exist.

6) Surface wave estimates now are provided operationally provided using numerical models and surface wind fields. Surface height data from satellites is used to validate and improve estimates and for climatologies; the collection of such data should continue.

7) Ocean productivity estimates are derived from ocean color measurements. The satellite system Sea-viewing Wide Field-of-view Sensor (SeaWiFS), operated by a commercial vendor, is the tool from which ocean color data are derived. There is the need to continue this quasi-operational testing and to add systematic, improved in situ observations.

3.2.2 The upper ocean.

3.2.2.1 Design

The upper ocean is a buffer to the exchange of heat and other properties between the atmosphere and the interior of the ocean and thus provides the first level of "memory" for the ocean-atmosphere system. The upper ocean is characterized by prominent seasonal to interannual signals suggesting that observation of the upper ocean will be important for prediction and regular monitoring of climate variability over these time scales. The objectives are:

1) To provide upper ocean data in the tropical Pacific for the initialization and verification of models for ENSO prediction.

2) To provide upper ocean data globally for the understanding and description of ocean variability and for the initialization and development of present and future models aimed at climate prediction on seasonal to interannual time scales.

3) To provide global data for monitoring, understanding, and predicting variations in upper ocean temperature and salinity at time scales from daily (for operations) to decadal (for climate change).

3.2.2.2 Status

In support of needed upper ocean observations the U.S. is a partner in several operational components, one ongoing pilot program, a major international research program and several proposed pilot programs to assess operational capabilities and to determine additional needs.

1) Through NOAA, and with assistance from Japan, an operational ENSO observing system is now being supported with the purpose of obtaining data from the tropical Pacific Ocean for the initialization and verification of models for ENSO prediction. This component is performing well as evidenced by the prediction of the last El Niño, and it should be continued. Needed in addition to in situ data are precise sea surface height and surface vector wind measurements from satellites. Continuing system evaluation is needed as is continuing support for this component and required improvements. This system is being expanded into the Indian and far western Pacific oceans with cooperation from Japan.

2) As part of the international CLIVAR (climate variability and predictability) program, the U.S., together with France and Brazil, are assessing the need for sustained upper ocean data outside the tropical Pacific for understanding, describing, and predicting climate variability on seasonal to interannual scales. The Pilot Research Array in the Tropical Atlantic (PIRATA) is a pilot project in the tropical Atlantic Ocean to examine such needs.

3) At present there is no adequate observing system for upper ocean temperature and salinity and their variability. The U.S. contributes via its research programs to an international "ship-of-opportunity" system from which expendable temperature (and sometimes salinity) profilers are deployed with the data being delivered in near real time via satellites. This sampling is limited to tracks and times of willing merchant vessels, and, for the most part has no operational source of support. Repeated high-resolution temperature sections from these volunteer observing ships can be both effective and efficient at measuring heat transport on basin scales, thus providing crucial diagnostics of the climate system and its long-term change.

   To obtain a more global, though broader scale, coverage of both temperature and salinity, a new pilot project called Array for Real-Time Geostrophic Oceanography (ARGO) is planned, with U.S. support from NOAA. ARGO will deploy and maintain a global array of profiling floats, capable of making profiles of temperature and salinity through the upper water column as well as estimating the horizontal currents at their deep resting depth (say 2000 m).

4) An international pilot initiative, called the Global Ocean Data Assimilation Experiment (GODAE), is planned for 2003-2005 to globally assimilate in situ and remote physical data including the ARGO data, with the following purposes, among others:
   - To demonstrate feasibility of a global observing system,
   - To develop optimal observing strategies, and
   - To provide data for initialization of climate models and boundary conditions for finer scale models, such as coastal zone models.

There is the need for enhanced capability for modeling and data assimilation within the U.S. ocean science community; it is within that community where many of the observing system products will be developed and refined and studies to improve efficacy of the system carried out.

3.2.3 The interior ocean.

3.2.3.1 Design

The interior ocean is characterized by its capacity to sequester heat, fresh water, carbon and other chemicals from the surface layers and delay exchange for long periods (from decades to perhaps 1000s of years). Deep ocean observations are essential for monitoring and detection of low frequency variations and changes that may be related to anthropogenic forcing of climate. The focus here is more on monitoring, understanding, and validation of model simulations than on prediction. The objectives are:

1) To determine the changes in oceanic inventories of heat, fresh water, and carbon on large space and long time scales.

2) To describe large-scale ocean circulation and transports and changes in selected physical and biogeochemical properties of the ocean (particularly heat, fresh water, and carbon) on long time scales and to understand and attribute these changes to natural and/or anthropogenic causes.

3) To estimate regional and global long-term change in sea level due to climate change; in particular that arising from greenhouse gas warming.

3.2.3.2 Status

The World Ocean Circulation Experiment (WOCE) provided the global perspective for ocean inventories of heat, freshwater, and carbon during the 1990s. The WOCE sampling was in terms of vertical sections of properties across all of the major ocean basins. Several of those sections repeated earlier observations, thus giving evidence of long-term variability.

1) There is considerable justification, and initial plans, for continued surveys of the deep oceans on decadal time scales. The data are needed to establish long-term trends of inventories within the ocean and to improve the modeling of exchange of carbon dioxide between ocean and atmosphere. This will provide information for the IPCC process and reduce uncertainties in global warming scenarios.

2) These same decadal surveys will provide a base, to which other observations may be added, for estimating large-scale ocean circulation and its transports of heat, fresh water, and carbon. Such observations should include long time series stations to sample the ocean over the full water column at selected locations.

3) The required precise satellite measurements of sea surface height are now available; their continuation is necessary. Needed now is to have some 30 high quality tide gauges geocentrically located in an earth reference frame.

3.3 Coastal Observations

3.3.1 The Challenge

Coastal waters encompass a complex mosaic of relatively shallow, interacting systems from rocky intertidal shores, tidal wetlands, estuaries, bays and sounds to the Great Lakes and the open waters of the continental shelf. They are subject to inputs of energy and materials from terrestrial, atmospheric, oceanic and anthropogenic sources. As discussed in "Priorities for Coastal Ecosystem Science" (NRC, 1994) and listed in Table 3.3-1, expressions of these inputs in coastal waters include the following:

1) nutrient enrichment, oxygen depletion, harmful algal blooms, chemical contamination and fish kills;
2) habitat loss, shoreline erosion, and increases in the susceptibility of coastal communities to natural hazards; and
3) declines in living marine resources, loss of biodiversity, and invasions of nonindigenous species.

In addition to the effects of natural hazards on coastal communities, sea ice and icebergs, surface waves (sea state), and sea level are expressions of external forcings that significantly influence human activities in coastal waters, from safe navigation and marine operations to recreation.

As indicated by the broad spectrum of changes given in Table 3.3-1, human activities and coastal ecosystems are having significant mutual impacts All levels of government recognize the need to improve understanding and prediction of both the effects of the coastal environment on human activities and the impact of those activities on the environment. Mitigating these effects and managing impacts are all dependent on improved coastal ocean observations and more timely dissemination of products derived from them.

Past efforts to monitor coastal waters and determine the causes and consequences of environmental change and variability have been developed case-by-case by different agencies and institutions to address specific issues and mission-based goals. The result is a plethora of programs that employ different platforms and methods, make measurements on different time and space scales, and use different data management systems. This approach has had little success in differentiating the effects of human activities from natural sources of variability, largely because it is difficult, and often impossible with existing information, to integrate data for a coherent evaluation of environmental conditions on either regional or national scales in a timely fashion. The scarcity of observations on coastal ecosystems of sufficient duration, spatial extent, and resolution and the lack of real-time data telemetry, assimilation and visualization are major impediments to the development of a predictive understanding of environmental variability in coastal waters. There is a clear need to design and implement an integrated coastal ocean observing system that addresses the mutual impacts of the environment and man's activities and links observation, synthesis, and applications in more effective ways.

Table 3.3-1. Nationally and globally ubiquitous indicators of environmental change in and human uses of coastal waters.

OPERATIONAL CATEGORY	INDICATORS OF CHANGE
Preserve & Restore Healthy Ecosystems Manage Resources for Sustainable Use	declining living marine resources
	oxygen depletion (hypoxia, anoxia)
	harmful algal blooms
	fish kills
	habitat loss (e.g., wetlands, sea grasses, coral reefs)
	diseases in marine organisms
	growth of nonindigenous species
	loss of biodiversity
	temperature & salinity distributions
Mitigate Coastal Hazards	loss of property and human life
	lack of economic stability
	higher insurance rates
	sea level rise
	coastal erosion
	susceptibility to natural hazards
Safe & Efficient Marine Operations	loss of property and human life
	spills of hazardous materials (oil, chemicals, radioisotopes)
	introduction of nonindigenous species (ballast water)

Protect Public Health	disease
	toxicity
Improve Regional Meteorology	inaccurate weather forecasts

3.3.2 Design

The major goals of the coastal component of the observing system are to develop a predictive understanding of the effects of environmental variability on human activities and interests and the impacts of human activities on coastal waters and the living resources they support.

Documenting and predicting the effects of human activities in coastal waters will require an integrated system that encompasses both oceanic and terrestrial observing systems.

The coastal ocean observing system must not only capture the full spectrum of environmental responses to external forcings from oceanic, terrestrial, atmospheric and anthropogenic sources (the temporal and spatial dimensions of variation), it must provide the information required to determine the causes and consequences of change and to predict change in a diversity of complex, interacting systems (CENR, 1997). In considering these requirements, the design of the coastal component must recognize

- the importance of quantifying inputs of energy and materials (sediments, nutrients, contaminants, organisms) from terrestrial, atmospheric, oceanic and human sources;
- the importance of geomorphology and depth in governing the response of coastal ecosystems to external forcings;
- the extent to which environmental conditions in U.S. coastal waters are analogous to conditions elsewhere in the world;
- the semi-enclosed nature of inland seas (estuaries, bays, sounds and the Great Lakes) and their proximity to land relative to the more open nature of the coastal ocean (the EEZ) and its proximity to the deep ocean;
- differences in the scales of variability that characterize coastal waters (see section 2.2); and
- the importance of the food web (trophic dynamics) to the sustainability of living marine resources.

Given these considerations and the requirements of both documenting and predicting patterns of change, the observing system will consist of five key elements:

(1) remote sensing (from aircraft, satellites, and fixed platforms, e.g. high frequency radar) to capture the spatial and temporal dimensions of change in surface properties,

(2) in situ measurements to capture changes in time and depth (moored instruments, drifters, AUVs, ships),

(3) index sites to develop the models required to link observations to products in the form of predictions and early warnings,

(4) real time telemetry and data assimilation for timely access to and applications of environmental data , and

(5) an effective data management system that accommodates the disparate coastal observation data systems/sources.

There is a common set of core properties that, if measured with sufficient resolution in time and space, will serve many needs from forecasting wave heights in the coastal ocean and nowcasting water depth in major ports and harbors to controlling nutrient inputs to coastal waters and fisheries management. The goal is to design an integrated observing system for coastal waters that will achieve this end and to build upon existing networks and programs where appropriate.

The requirements for data on physical processes of coastal waters are similar to those of the open ocean (changes in sea surface temperature and salinity fields on daily to decadal scales; surface fluxes of heat, water and momentum; surface wind stress, waves and circulation patterns) with the important exception that the spatial and temporal resolution of measurements must be finer. *These commonalities provide the framework for building the fully integrated system (open ocean to inland sea)* and will not be repeated here (see section 3.2). Given, the physical setting described in 3.2, section 3.3.2.1 describes those aspects of the observing systems that are required to detect and document the temporal and spatial dimensions of change in coastal waters. Section 3.3.2.2 describes what must be done to transform measurements into products.

3.3.2.1 Temporal and Spatial Dimensions

Remote Sensing

Remote sensing is a critical tool for obtaining spatially synoptic measurements of the status of coastal marine systems. Examples are: phytoplankton biomass and productivity from ocean color, sea surface temperature from infrared and microwave portions of the electromagnetic spectrum; circulation from and wave spectra from altimeters; sea surface winds from scatterometers; and sea ice from visible, infrared and microwave portions of the electromagnetic spectrum. The assimilation of remotely sensed data and the continued improvement of coupled biological-physical models for transforming measurements into products (e.g., predictions of environmental change, analysis of the efficacy of management actions mitigating coastal eutrophication) are particularly important. Advances in both modeling and remote sensing will require (1) better numerical procedures for calibrating and representing data in coastal waters; (2) fine time and space resolution to resolve features with dimensions of 100 m associated with important physical and biological features in coastal waters on diurnal and semi-diurnal scales; and (3) integration of in situ time series measurements with spatially articulated remote observations for more accurate documentation of time changes in spatial distributions.

In Situ Measurements

The selection of core properties and scales of measurement have been the subject of many workshops and reviews by the NRC (e.g., Vincent et al., 1993; U.S. GOOS, 1996; CENR, 1997). Table 3.3-2 gives a consolidated list of key properties that can be measured reliably now and which are related to most of the indicators of environmental change listed in Table 3.3-1. Measurements of many of these properties will be essential for periodic updates envisioned for the section of the "National Ecosystem Report" that addresses the status of coastal marine, great lakes, and estuarine ecosystems (see section 4). However, with the important exception of chlorophyll-a concentration, most of the important biological properties cannot be measured by either remote or in situ sensing technologies, or the measurements themselves are labor intensive and time consuming, e.g., presence of harmful algal species and the toxins some produce; detection of diseases in marine organisms; the presence of nonindigenous species; and species composition and biodiversity of pelagic and benthic communities. High priority for the evolution of the national observing system will be placed on the development of new technologies that provide the means to measure such properties and disseminate data in a more timely fashion. Also essential is continued improvement in numerical models and the assimilation of data into models for new and improved products.

Selection of Sample Locations

At this time, even those properties that can be measured with existing remote and in situ sensing technologies are not measured with sufficient resolution, areal extent or duration to adequately describe the time and space dimensions of most indicators of change (Table 3.3-1). Coastal waters are severely undersampled. The problem of designing the network of monitoring stations required to capture the time-space dimensions of change can be addressed now by enhancing the existing observing systems (e.g., the NDBC network of meteorological buoys) to measure oceanographic (physical, chemical and biological) properties and to make measurements at more locations. Station locations and environmental variables to be measured will be determined through an objective assessment and numerical analyses that will consider the:

- distribution of people in the coastal zone;
- the susceptibility of coastal environments to natural hazards; and
- sampling requirements for (i) improving weather forecasts, predictions of natural hazards, and climatology and (ii) documenting changes in coastal waters caused by fishing, point and nonpoint discharges from coastal watersheds, and larger scale oceanic and climate variability.

In general, the density of monitoring sites will be lowest in offshore waters and highest in nearshore waters, especially in coastal waters in the proximity of dense population centers. Cross-shelf transects ("corridors") of measurements will be located to reveal the health and regional environmental trends of coastal waters.

Table 3.3-2. Key properties and processes.

Property or Process	Time Scale	Platform
air: winds, pressure, temp[1] surface waves	hourly	moored systems[2]
freshwater inputs	continuous	fixed platforms
sea ice/icebergs	continuous	ships, remote
ambient noise	continuous	moored systems
atmospheric deposition[3]	daily - weekly	moored systems
water level[4]	continuous	fixed platforms, remote
bathymetry	decadal	ships
currents	continuous	moored systems, remote
temp & salinity	continuous	moored systems, AUVs, remote
color (phytoplankton biomass)	continuous - daily - monthly	moored systems, AUVs, remote, ships
nutrients[5]	hourly - weekly - monthly	moored systems, ships
suspended solids, turbidity	continuous - daily - monthly	moored systems, remote, ships
pCO_2, O_2	continuous - monthly	moored systems, ships

plankton species	weekly - monthly	ships
zooplankton biomass	continuous - monthly	moored systems, ships
benthic species, biomass	yearly	ships, AUVs
recruitment indices	seasonally	ships
stock assessment	seasonally	ships
chemical contaminants	annually	ships, mussel watch

[1] Measurements over water;
[2] Includes surface (buoys) and bottom mounted instrumentation;
[3] Wet and dry deposition of nitrate, nitrite, ammonium;
[4] Currently measured by NOS and USGS;
[5] Dissolved inorganic nitrate, ammonium, phosphate and silicate.

3.3.2.2 Transforming Data into Products

Intensive measurements and modeling of physical, biological, and chemical processes at selected sites (index sites) will be needed to quantify causal relationships and to develop technologies and models required to enhance the ability of the observing system to detect and predict change in real time. Index sites are defined as "places for monitoring an ecosystem at a scale and intensity adequate to develop an understanding of the processes controlling ecosystem change" (CENR, 1997). The unique and critical aspect of index sites is that all of the major potential causes of environmental change are measured in the same systems where environmental responses of concern to society are also measured. Index sites provide the linkage between large scale survey and monitoring programs and the basic research required to understand causal relationships and predict change in coastal waters with known certainty. In this regard, index sites will also serve as test beds and pilot projects required to develop and test new methods and technologies that may be incorporated into the observing system.

Index Sites (e.g., Coastal Intensive Site Network, coastal Long-Term Ecological Research, National Estuary Program, National Estuarine Research Reserves) will be strategically located to determine how external forcings (e.g., inputs of water, sediments, nutrients, and contaminants from coastal drainage basins; changes in large scale ocean circulation patterns and wave spectra; atmospheric deposition) are propagated through coastal ecosystems and cause change. The current set of coastal index sites will be expanded into a network that include sites which: (1) are influenced by riverine discharge (which integrate the effects of human activities in coastal watersheds); (2) support major fisheries; (3) are representative of the kinds of ecosystems that comprise the U.S. coastal zone; (4) are influenced by marine operations; or (5) are sensitive to larger scale oceanic and climatic variability.

3.3.3 Status

Given here is a brief overview of the status of coastal ocean observing system elements in support of the observing system design considerations of the previous section 3.3.2.

3.3.3.1 Temporal and Spatial Dimensions

Many of the building blocks for achieving the goals of the coastal observing systems are in place. These include but are not limited to the following:

(1) NOAA's NDBC buoy and coastal marine (C-MAN) networks;
(2) NASA's Ocean Biology and Biogeochemistry Program;
(3) NOAA's CoastWatch Program;
(4) Resource Assessment programs of the NMFS;
(5) NOAA's National Status and Trends Program (e.g., mussel watch);
(6) USGS's National Water Quality Assessment (NAWQA) and National Stream Quality Accounting Network (NASQAN) Programs;
(7) The Coastal Component of EPA's Environmental Monitoring and Assessment Program (EMAP);
(8) National Ice Center (NIC) and International Ice Patrol (IIP) observing systems;
(9) Environmental data from U.S. Coast Guard (UGCG) Stations and Cutters;
(10) State and local environmental monitoring and assessment programs; and
(11) The network of coastal laboratories (NAML).

Coastal Ocean

The mission of the National Data Buoy Center (NDBC) is to operate networks of environmental monitoring platforms in oceanic and coastal waters that provide accurate and reliable data for the National Weather Service and other users. The existing NDBC network of coastal marine and offshore moored buoys provides a critical source of continuous meteorological and oceanographic data for the purposes of weather forecasting and warnings of natural hazards. In addition to support from the NWS, funding is provided by MMS, NASA, NOS, USCG, U.S. Army Corp of Engineers, and the U.S. Navy. NDBC operates 62 moored buoys and 52 fixed platforms (the Coastal Marine Automated Network or C-MAN). These stations are in coastal and offshore marine waters around the United States and the Great Lakes. The data are distributed in real time and are available on the Internet. Data collected include wind speed, direction and gusts; barometric pressure; air and sea surface temperature; and (from all moored buoys and some C-MAN stations) wave heights. The stations are fully automated and report meteorological and oceanographic data hourly through the Geostationary Operational Environmental satellite (GOES). An important feature of the NDBC network is that data acquisition and processing electronics suitable for in situ use are in place, and the data acquisition system can be easily adapted to include oceanographic sensors. NDBC has begun to enhance its sensor capabilities by incorporating additional measurements including continuous winds, relative humidity, currents, salinity, solar radiation, and ocean optics. This has been done through reimbursable funding rather than building a defined program of operational data collection for the coastal oceans.

Since its inception in 1987, the NOAA CoastWatch program has developed enhanced, low-cost workstations, display software, low-cost digital communications systems, a validation system, and a distributed national network of NOAA Laboratories and Offices to apply and locally redistribute environmental satellite data and data products (http://coastwatch.noaa.gov). The program delivers high resolution near real-time NOAA environmental satellite data products and in situ data to Federal, state, local, and tribal resource managers and marine scientists and educators. Digital, high resolution data covering U.S. coastal waters and Great Lakes are distributed via the Internet. Once data are delivered to the CoastWatch Regional Nodes they become available for local use to state, local and federal resource managers, scientists and educators and the general public. CoastWatch data products are available retrospectively through a remotely accessible (dial-up, or Internet) system at NOAA's National Oceanographic Data Center in Silver Spring, MD.

The need to assess the status of living marine resources of commercial and recreational importance and to determine the effect of harvesting on these resources has led to the establishment of a network of fishery monitoring programs throughout the nation's EEZ. These sustained measurement programs have now been in place for nearly four decades off the northeastern United States and for shorter periods in other regions. Standardized surveys are conducted regularly to assess the distribution, abundance, demographic characteristics (age and/or size composition), ecological inter-relationships, and other biological characteristics of all species vulnerable to the sampling gear. Physical measurements (temperature, salinity, meteorological observations) are also carried out in these monitoring programs in the territorial waters of the U.S. by the National Marine Fisheries Service. Sampling techniques are tailored to individual systems and species assemblages in different regions; sampling gears range from modified fishing trawls to hydroacoustic systems. Because of differing regional requirements and logistical considerations, a fully standardized sampling program throughout the nation has not been implemented. Nonetheless, these regional programs often span large geographical regions using carefully standardized methods within regions. For example, standardized surveys are conducted twice yearly on the eastern continental shelf from Cape Hatteras to the Gulf of Maine by NMFS.

These surveys provide invaluable information on changes in the abundance of fish and shellfish populations over time. When used in concert with information derived from commercial and recreational fisheries, the surveys are instrumental in determining the effect of exploitation on these resources. Information on changes in the physical environment is used in concert with these observations to separate the effects of human activities and natural environmental changes. As our ability to predict changes in the physical environment increases, the potential for making proactive changes in fishery management strategies in response will also be enhanced. The existing monitoring programs established for fishery management will contribute to the proposed national ocean observing system. Fishery management efforts in turn will benefit from the increased emphasis on sustained measurement of physical environmental variables that directly and indirectly affect the productivity of the sea and living marine resources.

<u>Inland Seas</u> (Estuaries, Bays, Sounds and the Great Lakes)

NOAA-NOS operates a network of approximately 185 water level measurement sites along the coastlines of the United States, Great Lakes, and on some Pacific islands. The sites provide the data required to observe and predict tides and water levels and to obtain and archive the data. The data are transmitted via GOES on a 3-hour reporting internal with telephone telemetry as a backup and for real-time applications. Many of the tide gauges are instrumented with additional sensors to measure air and sea water temperature, and barometric pressure. Recent upgrades were developed, with the support from the National Weather Service to add event-triggered random reporting to support the Tsunami Warning Program in the Pacific and Storm Surge Warning Program along the coasts.

In a related effort, the U.S. Army Corps of Engineers Waterways Experiment Station (WES) operates approximately 50 monitoring stations in U.S. coastal waters and harbors to provide directional wind and wave data for planning, designing, and managing coastal projects (including permitting and management of navigation and flood protection projects). Data are transmitted to shore via a submarine cable or radio to a shore station, then via a land or cellular phone to one of several data collection centers. Data are also stored in the underwater platform for later retrieval. Data are retrieved at 1 to 4 hour intervals, though real-time networking is available for observing episodic events, military operational applications, and diagnostics.

NOAA-NOS has developed the Physical Oceanographic Real-Time System (PORTS), a centralized data acquisition and dissemination system that provides (via telephone and internet) water levels, currents and other oceanographic and meteorological data from an entire bay or harbor for safe marine operations. PORTS provides real-time data on currents, water levels and temperatures, winds, barometric pressure, and air temperature. Data are updated at 6 minute intervals. PORTS data are or will be available for NOAA weather radio broadcasts, "smart" bridges on ships, Vessel Traffic Services (VTS) provided by the Coast Guard, and Electronic Chart and Display Information Systems (ECDIS). Pilot projects have been initiated in Tampa Bay, the Port of New York and New Jersey, San Francisco Bay, and Galveston Bay/Houston Ship Channel. PORTS also intend to provide nowcasts and forecasts of water levels and currents.

Resource assessment surveys in estuaries, bays and the Great Lakes are principally carried out by state resource management agencies and the National Biological Survey of the USGS. These surveys provide a counterpart to resource surveys conducted by NMFS and, as in the EEZ surveys, provide information on the distribution, abundance, age, size composition, and other biological attributes of organisms vulnerable to the sampling methods. The principal sampling gears include trawls, dredges, and hydroacoustic sensors. Physical measurements of temperature and other factors are taken in conjunction with the biological samples. In instances where the surveys conducted in inland seas are contiguous with those conducted by NMFS in the EEZ, coordinated sampling designs and integrated analyses are often carried out in support of stock assessment.

Under the Clean Water Act, the States are required to report biannually their assessment of water quality conditions within their states. In addition, more than 300 coastal communities discharge their treated wastewater into the ocean. They are required to monitor their effluent quality with some being required to monitor the effluents' impact on biological communities near their discharges regularly.

About 400 million cubic yards of sediment are dredged each year in the U.S. to keep the nation's waterways open. EPA designates sites for the disposal of dredged material. There are 87 active sites around the country including two in Alaska, four in Hawaii, five in Puerto Rico, and one in American Samoa. Sediment and water column samples are collected before, during and/or after dredged material disposal operations to assess the impact of dredged material on the site and water quality.

The threat that toxic contaminants pose to U.S. coastal, estuarine, and Great Lakes environments is being monitored by NOAA's National Status and Trends (NS&T) Program. This program, through its Mussel Watch Project, measures the current status of, and changes over time in, the levels of about 70 persistent toxic contaminants. Concentrations of toxic trace metals, such as mercury and copper, and organic contaminants, such as chlorinated pesticides, polychlorinated biphenyls, and polynucleated aromatic hydrocarbons, are measured in the tissues of bivalve mollusks on a regular basis at over 250 coastal sites including the Great Lakes. In areas where substantially elevated concentrations of toxic substances are detected, the NS&T Program carries out detailed surveys on the magnitude and extent of biological effects due to these chemicals to assess the ecological consequences of the toxic chemical contamination.

The Environmental Monitoring and Assessment Program (EMAP) was established in 1989 by EPA to "monitor the condition of the Nation's ecological resources, to evaluate the cumulative success of current policies and programs, and to identify emerging problems before they become widespread or irreversible." The objectives of EMAP are to (1) determine current status, trends and changes in selected indicators of the Nation's ecological resources on a regional basis with known confidence; (2) determine the geographic coverage and extent of the Nation's ecological resources with known confidence; (3) document causal relationships between indicators of natural and anthropogenic stresses (forcings) and indicators of the condition of ecological resources; and (4) provide annual statistical summaries and periodic assessments of the Nation's ecological resources. To date, the coastal component of EMAP has yet to be fully implemented and has been limited to regional pilot projects, e.g., the middle Atlantic region in 1997-1998 and the initiation of the Western Pilot Geographic Initiative in 1999.

Collectively, the Nation's coastal laboratories are a national asset with a wide array of intellectual resources and store of data and information on local and regional coastal ecosystems. As a group, they provide access to virtually every kind of environment that constitutes the land-sea interface. Under the auspices of the National Association of Marine Laboratories, the Directors of these laboratories (academic and government) are designing a laboratory network (LABNET) as a means of networking laboratories for more timely access to data and information and cost-effective monitoring of coastal waters. The goal of LABNET is to provide the infrastructure required to exchange and integrate data collected at different coastal laboratories on different time and space scales for nearly seamless analysis and visualization. Similar efforts that target more specific problems include a network of laboratories and reserves to document and predict changes in coastal ecosystems of the Caribbean (CARICOMP) and the Gulf of Mexico Program Consortium for Marine and Estuarine Disease (CMED/GMNET), a network of state agencies to document the spread of infectious disease and determine their causes and consequences.

3.3.3.2 Index Sites (Pilot Projects)

Programs that satisfy or could satisfy the criteria for a network of index sites include the following:

(1) Land Margin and Long Term Ecological Research Programs (NSF);
(2) Coastal Intensive Site Network (CISNet) (NOAA/EPA/NASA);
(3) National Undersea Research (NURP), National Estuarine Research Reserves (NERRS) and National Marine Sanctuary Monitoring Programs (NOAA); and
(4) National Estuarine Programs and associated monitoring activities (EPA).

A small number of intensive monitoring and research (index) sites have been established in coastal waters. In 1980, the NSF established the Long-Term Ecological Research (LTER) Program to conduct research on long-term ecological phenomena. Today there are 19 sites and all but 3 are located in terrestrial ecosystems. The land/ocean-margin component of the LTER program is a collaborative effort between the Division of Ocean Sciences in the Directorate for Geosciences and the Division of Environmental Biology in the Directorate for Biological Sciences. Land/ocean LTERs focus on major ecological questions related to linkages between terrestrial and coastal ecosystems including the causes of major ecological and environmental changes that influence land/ocean-margin environments and how the populations, communities, and ecosystems of the land/ocean-margin environment respond to these changes.

In March, 1997, the Federal Interagency Committee on Environment and Natural Resources (CENR, 1997) released the results of an extensive study that called for the establishment of a nation-wide network of index sites to provide standard information on the major environmental variables known to influence ecosystem health. EPA, NOAA, and NASA responded with the initiation of a cooperative program to establish a network of intensive, long-term monitoring and research sites in U.S. coastal waters and Great Lakes coasts, the Coastal Intensive Site Network (CISNet). Eleven pilot CISNet sites have been established with the shared objectives of (1) developing and evaluating indicators of environmental change in coastal ecosystems; (2) demonstrating the usefulness of a network of intensively monitored sites for resolving short-term variability from long-term trends; (3) identifying and quantifying causal relationships between human activities and environmental variability and change; and (4) developing and validating models that predict how the environment will change in response to anthropogenic forcings. CISNet sites are to achieve these objectives through the integration of intensive ground sampling with remote sensing and through a comparative analysis of index sites that are representative of (1) different kinds of human impacts to estuarine and coastal environments; (2) major biogeographical regions that define the U.S. coastline; and (3) major habitats such as estuaries, coral reefs, sea grass beds and rocky fjords.

The NOAA National Undersea Research Program (NURP) includes the Aquarius undersea habitat located in the Florida Keys. That observatory supports long-term studies on the environment and ecology of coral reef ecosystems, coastal water quality, and habitat change in response to human activity.

On the New York Bight shelf, the LEO-15 (Long-term Ecosystem Observatory at 15-m depth) site provides intensive spatial and temporal coverage of physical, chemical, biological, and geological processes within a 20 x 20 km area. An extensive array of near-continuous, real-time physical, chemical, and biological measurements are made on the bottom and in the water column at two stations serviced be an electro-optical cable and fixed nodes. Additional "guest" ports are available at the nodes for providing power and internet connection to additional instruments. LEO-15, and related activities elsewhere on the U.S. east coast, are operated by the academic community with support mainly from NSF, ONR, and the National Oceanographic Partnership Program (NOPP).

The diversity and distribution of NOAA's 22 National Estuarine Research Reserves provide a network of representative coastal ecosystems to assess the magnitude and extent of environmental change in estuarine systems in 19 states. Building on existing water quality monitoring programs at each site, this NOAA program has embarked on a systematic coastal monitoring program to address factors governing habitat change and ecological structure in estuaries.

In 1987, Congress established the National Estuary Program (NEP) to restore and preserve these unique bodies of water. The program currently includes 28 estuaries that represent 42% of the shoreline of the continental U.S. These program are in various stages of design and implementation. Each NEP is developing its own database management system. Each NEP begins with a characterization phase in which the current state of knowledge concerning environmental conditions and existing and anticipate problems are defined. In this context, a monitoring program is designed and implemented that is subjected to periodic review.

3.3.4 Recommendations

The broad goals of the coastal component of the observing system are (1) quantify inputs of energy and materials from land, air, ocean, and human activities and to (2) detect and predict the effects of these inputs on human populations living in the coastal zone, on coastal ecosystems and living marine resources, and on coastal marine operations. This includes providing the data required to periodically update the "National Ecosystem Report" on the condition of U.S. coastal ecosystems (CENR initiative). The following observing system elements are recommended.

(1) Obtain more accurate estimates of inputs of freshwater, sediments, nutrients and contaminants to coastal waters on local to regional and national scales through
  - long-term, continuous measurements of flow at more sites, and
  - more frequent sampling of key properties, including especially sediment load, nutrient concentration, and selected chemical contaminants.

Virtually every program in U.S. coastal waters that is intended to assess and understand changes in coastal water quality does not have sufficient quantitative data on inputs from coastal drainage basin of those materials that influence water quality and living resources. In particular, the number of streams and rivers that are monitored for inputs of fresh water, sediments, nutrients, and toxic contaminants is not sufficient to quantify inputs from land to coastal waters on regional to national scales.

(2) Improve marine meteorological forecasts and coastal circulation models; more timely detection of environmental trends; document the effects of human activities on coastal ecosystems; improve scientific information in support of fisheries management; and assess the efficacy of management actions through
  - the development of an integrated in situ and remote sensing observing system for monitoring and predicting change in selected species of living resources and the quantity and quality of coastal habitats (intertidal, seagrasses, kelp beds, water column, and sediments); and
  - the development of an expanded and enhanced network of moored instruments in inland seas (estuaries, bays, sounds, the Great Lakes) and in the open waters of the EEZ for sustained, synoptic measurements of meteorological (including atmospheric deposition) and oceanographic (physical, chemical, and biological) properties deposition at more locations.

A recent NRC review (1998) emphasized the problem of undersampling as the main impediment to improving weather forecasts and early warnings of coastal hazards and strongly recommends that the number of stations and measurements be significantly expanded. The problem is even more severe for issues related to coastal ecosystem health and sustainable living marine resources. An expanded and enhanced network designed and implemented according to the general guidelines given above (3.3.2) and incorporating existing and emerging technologies for in situ measurements of optical, chemical and biological properties will provide the basic skeleton for the in situ measurement program of the coastal ocean observing system.

Fisheries science and management is moving toward ecosystem-based approaches to developing sustainable harvesting strategies. Progress in ecosystem-based management approaches will require integrated measurement systems, data bases, and modeling.

(3) Develop a network of coastal index sites (pilot projects) to
- quantify the causes and consequences of environmental variability in coastal waters, and
- improve predictions of environmental change and human impact in key locations.

Intensive measurements and modeling of physical, biological, and chemical processes at selected sites (index sites) will be needed to quantify causal relationships and to develop technologies and models required to enhance the ability of the observing system to detect and predict change in real time. Index sites provide the linkage between large scale survey and monitoring programs and the basic research required to understand causal relationships and predict change in coastal waters with known certainty.

(4) Improve the safety and efficiency of marine operations through
- a more comprehensive and integrated program of in situ and remote measurements of water levels, surface waves and currents, and
- timely dissemination of nowcasts and forecasts in all major ports and other coastal waters used for marine operations.

(5) Document changes in water depth (nearshore shallow water and the deeper waters of the EEZ) and shoreline topography through
- frequent high resolution topographic shoreline and nearshore bathymetric surveys, and
- less frequent systematic, high resolution bathymetric surveys of the continental shelf.

(6) Integrate distinct sea level observing systems (from measurements to data management) conducted in coastal waters.

4. Future Development and Integration of the U.S. Ocean Observing System

This section describes the approach by which the observing system design will be completed and full integration of the components will be ensured as we complete the design and implement the system.

It is clear from Section 3 that plans for different elements of the system are at different stages of development. In support of some needs, rather complete observing system designs have been articulated and considered, and implementation can proceed with relative certainty that desired results will be forthcoming. For some needs, the design of required observing system components is less complete. Although implementation can proceed, further design work is necessary before the full scope of the required components is articulated.

There are shortcomings regarding true integration and plans for attaining an integrated system. One example of a shortcoming is the lack of quantitative studies of trade-offs among different measurements/technologies used to obtain measurements of needed variables (e.g., between various technologies being used for measurement of sea surface temperature). Remedies for this deficiency include statistical studies of attainable levels of accuracy via differing mixes of measurements or use of numerical ocean models to perform studies of the efficacy of competing technologies/approaches. One can also assess the relative merits of alternative approaches by considering the impact of differing measurements/technologies on attaining a needed product versus the difficulty (i.e., feasibility, cost, etc.) of making the measurement (OOSDP, 1995; Nowlin et al., 1996; Andersen, 1997). Another example of a shortcoming, mentioned earlier, is the separation of observations into open ocean and coastal components. It is likely that some of these components will be merged once designs for the coastal component are completed and capabilities for the management of coastal data are commensurate with those for open ocean data.

The strategy is to continue steady growth of the ocean observing system with an accelerated time table for strengthening and building the coastal observing system. Because of the complexities of coastal environments and the need for synoptic physical-biological-chemical measurements, the design and development of the coastal observing system will be an evolving process as goals become more clearly defined and new technologies, tools and approaches are incorporated into the system. Although there is much to do to develop a fully operational observing systems for coastal waters, enhancements of emerging observing systems over the next 1-3 years will provide the skeleton framework for an observing system for coastal waters.

4.1 Relation to the international Global Ocean Observing System

With active participation from U.S. individuals, institutions, and agencies, an international framework for ocean observations is being designed and implemented from which the U.S. ocean observing system can benefit and to which it can contribute. This framework is embodied in the Global Ocean Observing System (refer to strategic plan and The GOOS 1998). Characteristics of GOOS also are reflected in the other global observing systems being designed and implemented: the Global Climate Observing System (GCOS) and the Global Terrestrial Observing System (GTOS).

These three observing systems, together with the sustained ocean measurements required by large research programs (e.g., those of the WCRP and the IGBP), constitute the Integrated Global Observing Strategy (IGOS), a concept conceived by the space agencies of the world and embraced by the observing systems and their sponsors.

On behalf of both GOOS and GCOS, the Ocean Observing System Development Panel (OOSDP) working between 1990 and 1995 developed a design for an ocean observing system for climate. The measurements required for this purpose, together with those already being collected in support of national security and forecasting of weather and surface ocean conditions encompass most of the global observations needed for an observing system.

The OOSDP was replaced in 1996 by the Ocean Observations Panel for Climate (OOPC) reporting to GOOS, GCOS, and the World Climate Research Program. That panel has continued to refine the design for ocean climate observations and has begun to assist with implementation. The U.S. will participate in the implementation and future refinement of that plan which is taken as a basis for the open ocean component of the U.S. plan.

Through its Coastal GOOS Panel chaired by Tom Malone, the international GOOS Steering Committee plans to have a complete, integrated plan for coastal observations, including preserving healthy coastal environments, promoting sustainable use of coastal resources, mitigating coastal hazards and safe, and efficient marine operations, by the summer of 2000. The U.S. GOOS Office and Steering Committee are making significant contributions to the completion of that design. When a fully articulated, well-considered design is complete, priorities for implementation of the complete system will be clearer.

4.2 Relation to the Committee on Environmental and Natural Resources

In response to a request from the Executive Branch, The Committee on the Environment and Natural Resources (CENR) of the National Science and Technology Council is developing a "report card" on the status of the nation's ecosystems, including coastal/marine ecosystems and those in the Great Lakes. The categories to be reported on include: (1) system extent; (2) landscape patterns; (3) management use and restrictions; (4) food and fiber production; (5) recreational use; (6) native species; (7) invasive species and disease; (8) primary productivity; (9) structure, composition and condition; (10) essential chemicals and nutrients; and (11) chemical contaminants. The coastal component of the U.S. ocean observing system will provide the data required to periodically update the report card and to resolve the effects of local to regional human activities from natural variability and the effects of larger scale changes in oceanic circulations, meteorological events, and global climate change.

In a proposed framework for research and monitoring, the CENR report describes a scaled index site approach to monitoring terrestrial biomes and ecosystems of the land-ocean margin. Highlights of their recommendations include (1) increase the use of integrated *in situ* and remote sensing for detecting and evaluating status and trends; (2) evaluate existing monitoring efforts for coverage of environmental issues, resources, and geographic areas; (3) initiate monitoring programs to monitor critical regional and national resources or issues that are not addressed by current programs; (4) establish a network of index sites by integrating existing intensive monitoring and research sites and adding new sites as needed; and (5) make integration of environmental monitoring and research networks and programs across temporal and spatial scales and among resources the highest priority of the framework. To the extent possible, prototype index sites are to be developed through more effective communication and the integration and comparison of data generated by programs that are currently in place. The intent is for these sites to become the backbone of a long-term, national monitoring network—a virtual network established through enhanced collaboration among existing monitoring programs.

5. Overarching Issues

A number of fundamental issues must be addressed to implement an effective operational ocean observing system. The observing system must include ongoing operational activities which are based on sound strategic planning. It must be able to adapt to changing requirements and technical capabilities in a tactically responsive fashion. It must be systematically evaluated on a regular basis. Assessment of its effectiveness will be determined by its ability to provide long-term continuity for the essential observations. Finally, a cost-effective implementation strategy must be developed that meets the diverse needs of the Federal agencies, the Congress, the academic and private sectors and the user communities.

5.1 Planning, Adaptation, and Evaluation

Strategic planning must involve setting measurement requirements for the system based on evolving user needs, evaluating research and technical developments for potential improvements, and examining revised sampling tradeoffs. Tactical response means responding quickly and thoughtfully to rectify identified performance shortcomings or to capitalize on new instrumental capabilities. These functions must be supported as a fundamental part of the observing system and carried out relentlessly.

Many elements of the required ocean observing system already exist. A critical initial task is to integrate these activities and to develop and carry through with effective data management activities. Deciding what elements to add to the system and when requires setting priorities. Priority must be based on user needs and on proven readiness.

There is a natural, generic sequence of events leading to the inclusion of a specific element into the integrated national ocean observing system. The generic sequence in time order is:

1. Development of an observational/analysis technique within the research and/or operational communities.
2. Community acceptance of the methodology gained through pilot projects demonstrating the utility of the methods and data.
3. Pre-operational use of the methods and data by researchers, application groups, and other end users, with particular emphasis on ensuring compatibility with legacy systems.
4. Incorporation of the methods and data into an operational framework for sustained use in support of societal objectives.

To illustrate the stages of progression through this sequence, examples are cited of (1) an observing system element that recently reached the operational stage, (2) an ongoing pilot project, 3) a sampling methodology fully vetted by the research community and now recommended as a pilot project, 4) a methodology used extensively by the atmospheric science community for research, analysis, and forecasting and now ready to be tested as an ocean observing system pilot project, and (5) an example of a sampling methodology still being explored by the research community but with potential as a future sustained observing system element. There are many such nascent observing system elements.

An example of an observing element that has progressed through research, pilot project, and pre-operational stages to become operational is the observing system in the tropical Pacific Ocean for detection and prediction of ENSO events operated by NOAA. (More information is given in Appendix 1.) The conceptual base for understanding ENSO events has origins four to five decades ago. The observational base for detection began to be developed in the 1960s. In the 1980s the Tropical Ocean-Global Atmosphere (TOGA) research program, supported by NOAA, NSF, and NASA, began to develop scientific understanding and predictive capability for ENSO events, particularly El Niños. An observing system pilot project in the tropical Pacific together with predictive modeling were initialized in the 1980s and maintained until the end of TOGA in 1995; this resulted in reasonable scientific understanding and significant predictive skill. NOAA then maintained the ENSO observing system element in pre-operational phase until two years ago when it became a sustained, operational component of the Global Ocean Observing System and the U.S. ocean observing system.

An ongoing multidisciplinary pilot project in the coastal ocean is the first of a series Long-term Ecosystem Observatories (LEOs) situated on the inner continental shelf off New Jersey to obtain high resolution, long-term measurements from a broad corridor of marine and coastal habitats, between the watershed of the Mullica River estuary to the deep sea. This pilot program is a test bed for new technologies designed to carry out unattended, long-term measurements over a range of disciplines. A 10 km electro-optic cable links two long-term outposts or nodes to a shore laboratory at Rutgers University and forms the basis for a real-time connection between the undersea world and the Internet. Beginning with a successful period of intensive operations during the summer 1998, this pilot has proved successful in attaining its ambitious initial objectives. More information is available in Appendix 2.

An example of a sampling methodology that has been developed and extensively used in research is the profiling float. This instrument drifts with ocean currents at a deep reference depth (say 2000 m) and periodically (say bi-weekly) cycles to the surface obtaining profiles of salt and temperature and reporting via satellite. This technology was developed as part of the World Ocean Circulation Experiment and tested globally as part of that program from 1990 to the present time. At present this technology is being proven further in the Atlantic Circulation and Climate Experiment described in Appendix 2. A recommended pilot project for the observing system is the Array for Real-time Geostrophic Oceanography (ARGO). This project is designed to provide enhanced global coverage of temperature and salinity in the upper 2000 m of the ocean as well as deep reference speeds during the period 2003-2005 by maintaining an array of profiling floats. (More information is available in Appendix 2.) Combined with other in situ and remotely-sensed data, the ARGO data set will be assimilated into numerical ocean models to demonstrate capabilities of an integrated ocean observing system for multiple users.

The third quarter of the 20th century saw meteorology evolve from a field of science and curiosity into one in which practical forecast skill was realized and accepted as a major objective. This was made possible by three factors: the evolution of scientific knowledge of the atmosphere, the ability to numerical solve equations with computers, and a global observational network. The Global Ocean Data Assimilation Experiment (GODAE) is seen as a one-time, major effort to demonstrate our ability to deliver timely, useful ocean products, derived from a global ocean dataset, and assimilated into skillful numerical models to extract the greatest benefit from the observations. This could move oceanography to state in which operational activities are undertaken routinely with useful and practical outcomes. The purposes of GODAE are manifold including:

- To demonstrate the feasibility of a global observing system to integrate disparate data sets and produce useful products,
- To estimate conditions within the global ocean on time scales of weeks to months and their variability,
- To develop optimal observing strategies, and

- To provide information for initialization of climate models and for boundary conditions for coastal zone models.

For more information, see Appendix 2. GODAE is recommended as a pilot project by both GOOS and GCOS Steering Committees as well as the Committee on Earth Observing Satellites (CEOS).

There are many examples of scientific observational methodology still in the research and development stage with potential for contributing to a user-based, sustained, ocean observation system. We give here only two examples of these nascent observing system elements. One is Acoustic Thermometry of Ocean Climate (ATOC). This research technique uses measured travel times of sound waves to estimate temperature along paths between transmitters and receivers and can also be used to estimate velocity components along the paths. The technique shows promise for estimating temporal differences in heat content within the ocean over long time and space scales, especially when combined with space-borne measures of sea surface height and numerical ocean models. A second nascent technology involves the use of Deep Earth Observatories on the Seafloor (DEOS) being developed as a major observing program focused on a diverse suite of earth and ocean science problems. Now in the planning and research phase, a system of seafloor observatories offer potential for obtaining long time series for various user needs.

Note that the recommendations for enhancements included in this plan have all been through a process of review by broad-based entities such as the National Research Council or the Global Ocean Observing System. No attempt has been made to include techniques just because they have completed stage 1 of this process; nor has an attempt been made to include all planned or ongoing pilot programs. To include all such potential future elements would be counter to the development of an integrated system. Clearly many such potentials exist and will be evaluated and included or excluded on their merits.

Requirements, knowledge, and techniques change with time, so there must be the mechanisms in place to ensure that the observing system changes accordingly, but without losing the required continuity of products (see next section). There must be resources (human and financial) to carry out ongoing review of user needs against system output, to assess and recommend new technical developments, and to examine strategic sampling tradeoffs needed to ensure that the observing system is properly operating and evolving to take advantage of new developments without compromising the long data records.

A steering group representing all partners in the observing system should be charged to review and evaluate progress, as well as maintain continuing oversight. Responsibilities should include revision of the integrated observing system plan based on revised requirements and regular review of progress toward meeting the requirements of the plan. One candidate for this function is the U.S. Steering Committee for the Global Ocean Observing System which has recently been appointed and is supported by federal agencies participating in sustained ocean observations. This committee is composed of government (Federal, state, and local), academic, and public (including business and non-profit) representatives with principal terms of reference (1) to identify user needs and match them with needed ocean observations and products and (2) to identify the highest needs for observations and products not currently being provided.

As the observing system matures, implementation and maintenance activities will become the major focus, and design tasks will become minor by comparison. A "tactical response unit" should be created that will have the resources to carry out those functions needed to support an observing system management in the continuing monitoring of performance and correction of problems. (This unit does not carry out evaluation of the system design; that is a strategic function and is a responsibility for scientific/technical leadership.) The emphasis must be on ensuring that quality controlled data and products are flowing at the requisite rates. This unit must have resources needed to carry out examinations and evaluations rapidly as needed. It should be separate from the operational units it is examining. This unit is envisioned as permanent, though it need not have a large number of employees.

5.2 Continuity

Continuity is key to a successful, sustained observing system. In addition to maintaining required operational observations over the long term, there must be an ability to incorporate--into those ongoing operations--additions and improvements resulting from research and pilot activities.

Within the U.S., there are multiple agencies, with distinct mandates, responsible for ocean observations. Likewise, the Congressional funding process for ocean observations involves many committees and staffs. This diversity of interest and multiplicity of responsibility is a complex issue, and it must be adequately resolved if we are to secure continuity of observing system elements. A resulting challenge is how to achieve an orderly transition of proven ocean observing systems from research-and-development support to operational support. This challenge, for example, has been met with varying degrees of success with regard to space-borne measurements.

Space-borne instruments make measurements that are required to complement in situ observing systems, and whose accuracy depends on high quality in situ data for calibration; and we must strive to ensure long-term continuity of key observations from both. Satellite measurements of particular importance to the oceans are sea surface temperature, ocean color, sea surface height, and surface vector winds.

Sea surface temperature is an example of a satellite measurement system which has successfully made the transition to be incorporated into the present series of NOAA polar-orbiting operational meteorological satellites. Ocean color is an example of a measurement system which is now flying as the result of a partnership with the private sector. For both sea surface temperature and ocean color, this transition to operations has built on a process-including both NASA and NOAA-that has extended over more than two decades. Looking to the future, requirements for both of these measurements will be met by an operational sensor to be flown on the National Polar-Orbiting Environmental Satellite System (NPOESS).

For sea surface height, the U.S. and French space agencies (NASA and CNES) have committed to launch a new satellite (JASON-1) in 2000 to continue the high-accuracy, high-precision altimeter measurements initiated by their joint mission TOPEX/Poseidon in 1992. However, commitments to a follow-on mission to JASON-1 have not yet been made. The flight of such missions require long lead times; and unless a commitment is secured within the next 18 months, it is unlikely that a follow-on mission could be ready for launch in 2003, the end of the design life of JASON-1. This would interrupt the continuity of this essential time series of global observations of sea surface height.

For the measurement of surface vector winds, there are commitments for three missions to fly scatterometers in the near term (NASA's QUICKSCAT in 1999, NASA's Sea Winds aboard the Japanese ADEOS-2 in 2000, and EUMETSAT's METOP in 2003). However, commitments for follow-on missions, with the demonstrated capability and the necessary spatial and temporal coverage, are needed in order to continue measurements of the global marine wind field. The next such commitment must be secured within the year, so that a follow-on mission could be available at the end of the two NASA missions.

Just as with sea surface temperature and ocean color, there is a critical need to plan for, and work to implement, the orderly transition of capabilities to measure sea surface height and surface vector winds from support as research-and-development activities in NASA to long-term operations in NOAA. Measurements of both sea surface height and surface vector winds meet research, operational, and policy needs, but the satellites cited above have been funded strictly as research missions. While there a capability for near-real-time access to data from these missions, there is a critical need for more active involvement by the operational agencies, including the provision of adequate funds for pre-operational use and pilot studies. And when such missions reach the stage where it seems clear that their products will be needed for the long term, the operational agencies need to become significant financial partners. In short, there is ample research-and-development 'push' to the partnership, but the operational 'pull' needs to be strengthened. Note that these comments apply equally well to the transition of in situ observing systems from research to operational support.

Looking to the future, scientific and operational requirements for sea surface height and surface vector winds need to be more strongly incorporated into planning for NPOESS. Just as NASA has successfully used advisory teams with its missions, NPOESS could significantly benefit from similar advisory teams comprised of appropriate users, engineers, and scientists; this comment applies equally well to any operational component of an observing system.

Clearly, appropriate guidance and oversight is needed to ensure sustained support for needed observations, both in situ and space-borne, and to enable needed observing system elements that have been developed and proven to be transitioned without loss of measurement continuity to operational support.

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Appendix 1: Observing System Elements by Agency

NOAA Elements

NOAA operates many coastal and global ocean observing elements in support of a wide range of requirements. These elements are summarized in narrative and tabular form.

1. Climate Variability. To support NOAA's climate prediction mission, primarily on seasonal to interannual time-scales, the major operational program is the ENSO Observing System. Complementing the ESNO Observing System are NOAA's environmental satellite systems, which provide regional and basin-wide observations of sea surface temperature and surface wind speed. This system consists of: some 70 moorings in the tropical Pacific (called the TAO array) that provide surface atmospheric and ocean mixed-layer observations; several hundred global Lagrangian drifting buoys in all the major ocean basins; a VOS XBT program of about 40 commercial ships; and a network of tide gauges. The resulting data are used in initialize climate models, verify model results, and monitor the evolution of the upper ocean. NOAA also maintains observing systems that are in the developmental stage, including a shipboard thermosalinograph effort; the Trans-Pacific Profiler Network, consisting of ten profilers in the equatorial Pacific; a Pacific upper-air sounding network on islands and ships in the Pacific; the Pan American Climate Studies Sounding Network of enhanced atmospheric observations; an ocean carbon-ocean tracer hydrographic program to determine global distributions of key chemical, biological, and physical tracers; a submarine cable providing estimates of Florida Current transport; a Voluntary Observing Ship CO_2 program of semiautomated systems to monitor pCO_2; an Atlantic Ocean pilot project (called PIRATA) of 12 buoys in the tropical Atlantic; and an Atlantic profiling float array to study processes important in establishing SST variability.

2. Marine Operations. NOAA operates several real-time observing systems to facilitate safe and efficient marine operations and address the diverse needs of maritime commerce. Along the nation's ocean and Great Lakes shorelines, NOAA's National Ocean Service operates the National Water Level Network, which includes almost 200 continuously operating water level measurement systems. At five extremely busy harbor entrances, NOS operates Physical Oceanographic Real-Time Systems (PORTS). These systems consist of acoustic Doppler current profilers with anemometers, packet radio transmission equipment, a data acquisition system and an information dissemination system. The real-time data information helps the users (e.g., vessel operators and masters, pilots, mariners, facility managers, etc.) make sound decisions regarding loading of tonnage, limiting passage times and a wide variety of related needs for safe and cost-effective navigation. In the coastal ocean and Great Lakes, NOAA's National Data Buoy Network provides real-time data on the sea state and meteorological conditions at over 100 buoys and several shore-based C-MAN stations. This information is critical to NOAA, state, and private weather forecasters and extremely useful to the public, fishermen and coastal mariners. Finally, a critical component of NOAA's support to marine operations is the early detection and tracking of significant marine weather events through NOAA's geostationary and polar-orbiting satellites.

3. Ensuring National Security. NOAA-NESDIS serves as the operational and command authority for the Defense Department's Defense Meteorological Satellite Program. NOAA's

environmental satellite data are shared in near real-time by formal agreement with the Department of Defense in support of the Air Force and the Navy's global and regional weather and ocean forecasting model prediction services. In times of national emergencies (both military and natural hazards response), NOAA provides enhanced local area environmental satellite coverage through NOAA's polar orbiting satellites worldwide and for emergencies affecting the western hemisphere, NOAA's geostationary satellites. National security interests involve not only military concerns, but also economic displacements that may result from natural hazards, global climate change and political upheavals. In situations involving immediate danger to human life, NOAA-NESDIS provides emergency environmental satellite coverage of local regions for direct use in relief efforts.

4. Managing Living Resources. During FY 1998, NMFS scientist from five Regional Science Centers spent over 3000 days at sea collecting routine information on the abundance, biology and ecology of U.S. living marine resources. In addition to at-sea survey activities, routine information on fish and marine mammal abundance is collected via aerial and streamside surveys. Four major programs (Coastal Change Analysis Program; Effects of Fishing on Essential Fish Habitat (EFH); Seafloor Characterizations to identify EFH and Habitat Areas of Particular Concern; and Monitoring of SAVs in Coastal Waters) provide routine observations on the habitats of managed species. In addition information on the ecosystems within which these stocks exist is required. Ecosystem information including data on physical and chemical oceanography, phytoplankton, zooplankton and forage fishes is collected through several programs: including the California Cooperative Fisheries Investigation (CalCoFI) off Southern California; the Marine Monitoring and Assessment Program (MARMAP) in the Northwest Atlantic; SEAMAP in the Southeast U.S.; and the Fisheries Oceanography Coordinated Investigations (FOCI) in the Gulf of Alaska and Bering Sea. These programs provide essential information on abundance and distribution of marine fish and invertebrates, and environmental changes which affect them.

5. Healthy Ecosystems. NOAA's NOS and NMFS conduct the National Status and Trends Program which measures the current status of and changes over time in the levels of toxic contaminants, including trace metals, pesticides, petroleum hydrocarbons, and other toxic organic contaminants. In addition, the effects of these compounds on fish and shellfish at about 280 locations in the U.S. Coastal and Great Lakes ecosystems is monitored. In areas where substantially elevated concentrations of toxic substances are detected. Detailed observations on the magnitude and extent of biological effects due to these contaminants are conducted. NOS also supports the National Estuarine Research Reserve System (NERRS) to monitor physical, chemical and biological parameters in 25 areas. The data are used to describe, track and predict long-term changes and short-term variability in the status, integrity and biodiversity of these areas. NOAA in cooperation with EPA and NASA has initiated the establishment of a nation-wide network of coastal and Great Lakes index sites to provide standard information on major environmental variables. Eleven pilot sites for this Coastal Intensive Site Network (CISNet) have been established with the objectives of: developing and evaluating indicators of environmental change; demonstrating the usefulness of such a network for resolving short-term variability from long-term trends; identifying and quantifying causal relationships between human activities and environmental variability; and developing and validating models of environmental change in response to anthropogenic forcings. NMFS in conjunction with the States and other Federal agencies coordinates the Marine Mammal Health and Stranding Network which collects and analyzes tissue samples

from stranded marine mammals for histopathology, contaminants and disease. NFMS also makes routine observations of fish collected in resource surveys for the presence of tumors or lesions that may indicate high levels of contaminants in the environment.

6. Mitigating Natural Hazards. NOAA's suite of sustained ocean observations provides urgently needed real-time data required for decision-making. In addition these data provide fundamental input to the predictive models used for the short-term warnings that NOAA must disseminate to the public and other users. In the coastal ocean and Great Lakes, NOAA's National Data Buoy Network provides real-time data from over 100 buoys and several shore-based C-MAN stations as described in the Marine Operations paragraph above. In addition, the Water Level Network (see paragraph 2 above) provides retrospective and real-time data on extreme water levels that may threaten coastal communities and commerce. To address the critical need for mitigating the threat of tsunamis along the U.S. West coast, NOAA operates the tsunami warning network, which includes newly installed real-time sensors for detecting the passage of tsunamis most likely to impact highly vulnerable coastal communities.

7. Ensuring Public Health. NOAA conducts several monitoring programs related to properties of concern for protection of public health. In cooperation with the EPA and states along the southeastern U.S. coast, NOAA is monitoring the levels of the toxic dinoflagellate, *Pfiesteria piscicida,* and related water quality properties to determine the threat posed to human health and the ecosystem by this organism. The National Marine Fisheries Service conducts a Seafood Inspection Program in conjunction with the Food and Drug Administration and the States to ensure that U.S. Seafood products are safe for consumption.

In column 1 of the table are given NOAA observational requirements and the areas of societal need support by each type of requirements. (The need areas are indicated by numbers: 1. Detecting and forecasting oceanic components of climate variability; 2. Facilitating safe and efficient marine operations; 3. Ensuring national security; 4. Managing living resources for sustainable use; 5. Preserving and restoring healthy marine ecosystems; 6. Mitigating natural hazards; and 7. Ensuring public health.) In column 2 are given the related observing system elements; they are designated either as operations (O, i.e., long-term support is available for sustaining the observing system) or developmental, (D, i.e., the transition from research to operations has not yet been made, but strong justification exists for either continuing the developmental activities or transitioning from research to sustained observations). Inadequacies in the observing systems are noted in Column 3 with some suggested remedies.

NOAA Observations Requirements (Societal Needs)	Observing System Elements (Status)	Inadequacies/Solutions
Global and coastal surface atmospheric and oceanic data for weather and climate forecasts (e.g., wave heights, currents, winds, rainfall, visibility, air-sea fluxes, nutrients, etc). (1, 2, 3, 4, 5, 6, 7)	National Data Buoy Network, including moored buoys and C-MAN shore stations (O)	Can support additional ocean and atmosphere sensors; poor spatial coverage can be corrected by additional sites. Data need to be integrated into high resolution coastal observing network
	VOS (ca, 1500 ships) (O)	Poor data quality and data transmission
	TAO (O)	Can support additional atmospheric sensors
	Satellites (O)	Can support additional high-resolution, rapid update sensors on geostationary satellites. Continuity in surface wind observations and altimetry not guaranteed
	Trans-Pacific profiler network (D)	Increased coastal coverage needed
	PORTS	Additional systems needed at high-traffic port/harbor entrances
Air-sea fluxes of heat, water vapor (1)	Satellites (O)	Additional communication channels would allow simultaneous observations on available sensor spectral bands
Air-sea fluxes of CO_2, halocarbons (1)	VOS observations (D)	Increased coverage needed
Oceanic inventories of CO_2 (1)	Research cruises of opportunity (D)	Not sustained

NOAA Observations Requirements (Societal Needs)	Observing System Elements (Status)	Inadequacies/Solutions
Sea surface salinity, sea surface temperature (1, 3, 4, 5, 7)	VOS (O) Drifters (O) Satellite (O)	Low quality SST/implement hull sensors, limited SSS/increase coverage Deploy more SSS sensors Clouds and aerosol problems/ requires continued in situ observations Underutilization of geostationary satellites for coastal applications
Sea level (1, 2, 6)	National Water Level Network (O) GLOSS (O)	Both network modernization and more complete spatial coverage required
Subsurface temperature and salinity (1, 3, 4)	TAO (O) VOS (O)	Limited salinity data Limited salinity data/implement profiling float array
Ensure healthy coasts through monitoring of contaminants, nutrients, ecosystems,. Turbidity (4, 5, 7)	4 sites for benthic observations; many estuarine fresh water sites (D) Satellites (O) Marine Mammal Health and Stranding Network, shore-based (O) Fish contaminant monitoring, ship-based (O) Mussel Watch site network for contaminants (O) CISNet pilot sites (D)	More sites needed in critical areas (e.g., chemical contaminants, pathogenic organisms, harmful algal blooms) Geostationary satellites can support additional sensors (e.g., chlorophyll, turbidity, nutrients, etc.) More extensive geographic coverage. Better training for observers More extensive geographic coverage
Tsunami warning forecasts (2, 6)	Pacific rim array of tide gauges and other sea level sensors (O)	Good for detection, not for forecasting, need detectors in source regions and improved telecommunications

NOAA Observations Requirements (Societal Needs)	Observing System Elements (Status)	Inadequacies/Solutions
Information management (1, 2, 3, 4, 5, 6, 7)	OAR ad hoc system for real-time data distribution (D)	More effective real-time data dissemination required
	Real-time data from satellites (O)	New data volume will stress ability to provide real-time access and to store data
	Delayed mode data from data centers (O)	User access hindered by multiple formats and deterioration of many historical archives
	Coast Watch for real-time satellite and coastal buoys (O)	Lack of access to forecast and model results limits integration of remote and in situ data
		Lack of compatible protocols and formats for land and ocean data limits integration
Manage sustainable living resources in the EEZ (4, 5, 7)	Fishery-independent surveys from ships, aircraft, submersibles (O)	Insufficient coverage for some stocks. Need increased number of surveys and quiet research vessels. Advanced sampling technology required to improve accuracy
	Marine mammal and sea turtle abundance surveys from ship, aircraft, land-based observations (O)	Insufficient coverage for some stocks
	Habitat monitoring from satellite, ship and land-based observations (O)	Observations insufficient to meet requirements under the Sustainable Fisheries Act
	Ecosystem monitoring and assessment using ship and satellite based observations (O)	Increased observations at lower trophic levels required. Needs expansion of include all U.S. large marine ecosystems
	Ecosystem process studies using ship and satellite observations (D)	Transition to operationalize monitoring of key processes
Sea ice forecasts (2)	Satellites, drifting buoys (O)	Cloudiness in polar regions limits passive sensor data, active sensors lack spatial resolution

Navy Elements

The national-security need for ocean observations was originally built around two premises:

1. The need for open ocean waves, weather and ice forecasts to support safety of fleet operations, and
2. the Cold War requirement for open-ocean temperature, salinity and sound velocity measurements to support sonar performance in the tracking of Soviet ballistic-missile submarines.

The national security-supported ocean observation system has, therefore, included heavy emphasis on open-ocean temperature, salinity, winds and ice observations. Major elements of that system include:

* Expendable temperature probes.

  Navy ships and aircraft routinely take expendable bathythermograph (XBT) measurements throughout the world during fleet operations using probes that measure temperature with water depth as the probe falls through the water column.

* Satellite temperatures.

  Temperatures at the sea surface are now routinely measured by infrared sensors on satellites. Because of the national security need for real-time global data, the Navy acts as a national Core Processing Center for sea surface temperature (SST) data from various satellites and disseminates the data to civil and military users worldwide.

* Other satellite measurements.

  Satellite altimetry measures the height of the sea surface, which is affected by temperature/salinity differences and by ocean currents. Scatterometry uses sea surface roughness to infer winds. Products include sea-surface topography, currents, eddies, wave heights, and surface wind-speed and direction. Satellite altimetry and scatterometry observations (from the ERS-2 and TOPEX/POSEIDON satellites) are extremely useful in remote regions where ship and buoy measurements are not available.

* Drifting buoys.

  The Navy deploys about 220 drifting buoys annually in areas of high interest. They can measure surface atmospheric pressure, air and sea surface temperature, winds and waves, and surface currents, that provide excellent "ground-truth" for satellite observations, as well as water temperature with depth, and "ambient" (background) noise levels that support Navy sonar operations. The observations are sent hourly via satellites.

* Ice observations.

  Navy, NOAA, and the Coast Guard jointly operate the National Ice Center which provides global, regional, and local sea-ice analyses and forecasts, including ice edge, concentration, drift and thickness, for military and civil users. Ice observations come from U.S. and European satellites, U.S. and Canadian ice reconnaissance flights, and from specially instrumented buoys placed each year through the Arctic ice.

* Survey and research ships.

  The Navy has operated a fleet of dedicated military survey ships for decades. They principally collect:

  • "hydrographic" data (including water depth, bottom type, tides and currents) in coastal areas worldwide to improve and update nautical charts;

- deepwater bathymetry (water depth) and gravity measurements to support strategic submarine operations;
- physical oceanography (temperature, salinity, sound velocity), ambient noise, seafloor structure and sediment type to support sonar performance and acoustic surveillance arrays; and
- a wide range of other observations (water clarity, bioluminesence, currents, magnetics) that affect naval operations.

The Navy is also a major supporter of the nation's academic research fleet, and funds ocean observations for basic and applied research projects worldwide.

The national security needs for ocean data are now focused not only in the open ocean but also increasingly in the coastal waters of the world. Data from the open ocean through coastal waters, the surf zone, and over the beach are all needed to support modern naval operations. Because of the greater variability, shallow coastal waters require more observations in time and space. Of particular interest are water depth, sea surface temperature and temperature at depth, bottom type, waves, tides, currents, and coastal ambient (or background) noise. While the primary national security requirements for coastal ocean observations are in sensitive areas overseas, the diversity of environments in U.S. coastal waters provides many analogues of coastal systems overseas. For this reason, national security needs must play a significant role in design of the coastal observing system. Navy home-porting, and coastal training, test and exercise functions in U.S. waters require expanded observations.

Coast Guard Elements

The U.S. Coast Guard deploys and provides logistical support for ocean data buoys that make synoptic meteorological and oceanographic measurements for both the National Data Buoy Center and the National Ice Center. In addition, they make a number of other ocean or lake observations.

Vessel Traffic Service. The Coast Guard operates a Vessel Traffic Service (VTS) for nine port areas in the United States: VTS Berwick Bay, VTS Houston/Galveston, VTS Los Angeles/Long Beach, VTS New York, VTS Prince William Sound, VTS Puget Sound, VTS San Francisco, VTS St. Marys River, and VTS Louisville (seasonal). Each VTS is a service of active waterways management using advanced technology such as radar, closed circuit TV, differential GPS (DGPS), and VHF-FM radio communications. In addition, the VTS also receives information from various sources on predicted vessel movements, hazards to navigation, aids to navigation discrepancies, and other information of interest to VTS users. The VTS involves persons external to the vessel that receive, process, and communicate information related to the safe navigation of a waterway with a primary focus of public safety and protection of the environment. This information can be output as general advisories or in the form of specific recommendations to assist a vessel in avoiding hazardous conditions early on. Only on rare occasions will a VTS direct the movement of a vessel.

Sea Ice and Icebergs. The U.S. Coast Guard operates the International Ice Patrol (IIP) in the North Atlantic under provisions of the U.S. Code and the International Convention for Safety of Life at Sea (SOLAS). The IIP is supported by seventeen member nations, monitors danger from icebergs near the Grand Banks of Newfoundland during the ice season, and broadcasts the limits of all known ice. This information is used by ships for safe navigation and the most efficient route planning.

The Coast Guard participates with the Navy and NOAA in operating the National Ice Center which provides sea-ice analyses and forecasts using data from satellites, aircraft reconnaissance flights, and arctic buoys.

Meteorological Data. Coast Guard cutters send weather information to the Navy and NOAA. Coast Guard stations also send meteorological data to NOAA for use in analyses and forecasts.

Oceanographic Data. The Coast Guard International Ice Patrol deploys drifting buoys in support of iceberg/sea ice prediction. Currently observations of position and sea surface temperature are reported via satellite eight times per day.

The International Ice Patrol obtains water temperature profiles from AXBTs deployed by Coast Guard aircraft and sea surface temperature data made available by commercial ships. These data are sent to the Navy.

Coast Guard Polar icebreakers provide a number of oceanographic observations in the Arctic and Antarctic to Navy, NIMA, and/or NOAA databases. The reports include ocean temperature, salinity, bathymetry, and marine mammal data.

NSF Elements

Academic oceanographers supported by NSF have long recognized that the ocean and the underlying solid Earth cannot be studied adequately in a static manner by simple characterization over limited regions or for short periods of time. Processes that actively shape the Earth and hence impact society occur over a vast range of temporal and spatial scales and exhibit considerable covariance and dynamic interlinkages. Future investigations of the ocean and its interelationships with Earth as a dynamic system will require new approaches, including the establishment of long-term ocean observatories, building on and advancing well beyond the surface-ship expeditionary style that has dominated the marine sciences since WWII.

Ocean Technology and Infrastructure

NSF has invested significant funds over several decades in the areas of technology, instrumentation development and infrastructure. There are many examples of ocean observing instrumentation developed with the aid of NSF funds currently deployed. The ALVIN submersible is amongst the best known examples of deep ocean infrastructure which has been continually upgraded over many years to provide ever-improving, state-of-the-art, long times-series, deep ocean observations.

Technology development efforts are presently underway at three observatory locations including: the Hawaii Undersea Geo-Observatory (HUGO)-automated submarine volcano observatory; the Hawaii-2 Observatory (H2O)-broad-band seismometer; and the Long-term Ecosystem Observatory (LEO-15)-broad array of sensing systems.

A major design study has been implemented in association with National Ocean Partnership Program (NOPP), for "NEPTUNE," a concept incorporating a fiber optic cable, linking a series of sea floor nodes capable of supporting real-time transmission of data and images from many hundreds of instruments. The Deep Earth Observatories on the Seafloor (DEOS) is another planning activity program initiated by the NSF in 1996, for observations beyond the reach of fiber optic cables.

Ocean Climate

Repeat Hydrographic Surveys. During the World Ocean Circulation Experiment (WOCE), a five-year "snapshot" of the global density and property field of the ocean was obtained. At the same time, numerous hydrographic sections were repeated on a regular basis to address overall structure, meridional overturning, and transport through particularly important "choke points."

Synoptic Density and Velocity Survey. During WOCE, a study (ACCE – Atlantic Climate and Circulation Experiment) using autonomous subsurface profiling floats is being carried out between Greenland and latitudes below the equator. ACCE has become the prototype for the Array for Real-time Geostrophic Oceanography (ARGO - see Appendix 2), which will provide a major part of the data base for an international Global Ocean Data Assimilation Experiment (GODAE – see appendix 2) to be carried out in the early part of the next decade.

A large array of autonomous floats under ARGO is planned, and it is likely that NSF will support a number of these as part of long-term climate research. Global Eulerian Observations (GEO) will complement ARGO and provide diagnostic and verification of the Lagrangian measurements, greatly reducing their uncertainties, and lead to more accurate representations of global heat fluxes.

Ocean Biogeochemistry

The first continuous time-series of particle flux in the deep ocean were inaugurated in 1977, by deploying moored sediment traps at the longstanding Hydrostation S located approximately 75 km south of Bermuda. By the early 1980's, the Oceanic Flux Program (OFP) observations surprised the oceanographic community with the observation that particulate flux to depth was not constant but rather varied seasonally with the cycle of plankton production.

In 1988, the National Science Foundation initiated funding for oceanic time-series stations in the North Pacific Ocean near Hawaii (HOT) and in the North Atlantic near Bermuda (BATS). These stations were initiated as part of U.S. JGOFS, as a response to the growing realization that an understanding of the role of oceanic processes in climate and global change would require both regional studies of marine carbon biogeochemistry and long-term time-series observations. During their first decade of operation, HOT and BATS have gained national and international recognition as the prototypes for oceanic time-series observatories. The CARIACO (Carbon Retention In A Colored Ocean) Program was initiated in November 1995, with the primary objective of studying the relationship between surface biogeochemical processes and the fluxes of carbon and nutrients in a continental margin setting influenced by seasonal upwelling.

In spite of their recognized importance, systematic, long-term biogeochemical and ecological observations of oceanic habitats are rare, even though these regions are arguably the largest ecosystem on Earth. The oceans play an integral role in the Earth's carbon, heat and water cycles.
Long-term biogeochemical/ecological time-series observations are needed to allow observations of key ocean processes at time scales, ranging from hours to decades.

Ocean and Coastal Ecosystems

Fish Stock Variability. The U.S. GLOBEC Northwest Atlantic-Georges Bank Program is designed to understand the population dynamics of key species on the Bank in terms of their coupling to the physical environment, predators and prey. The ultimate goal is to be able to predict changes in the distribution and abundance of these species as a result of changes in their physical and biotic environment as well as to anticipate how their populations might respond to climate change. Ongoing observations begun in the last decade will be required for the foreseeable future. An analogous U.S. GLOBEC Northeast Pacific Program (NEP) has begun to study the effects of past and present climate variability on the population ecology and population dynamics of marine biota and living marine resources.

Retrospective Analyses of Ocean Ecosystems – NSF has supported studies of existing ocean and coastal data sets, including the Continuous Plankton Recorder Surveys and the California Cooperative Fisheries Investigations (CalCoFI). NSF has also helped to support a series workshops, the purpose of which has been to mine all the historical data surrounding major fish stock explosions and crashes, subjecting them to extensive modeling exercises in an effort to prove or disprove the many speculative hypotheses established to explain them.

Coastal Ecosystems. NSF has long supported important coral reef and rocky shore time-series. These include studies of corals and algae on the Great Barrier Reef for 35 years, the ecology of reefs in relation to El Nino events in the eastern tropical Pacific since 1980, rocky shore sites for 22 years in Northern Massachusetts and on the outer coast of Washington State for almost 30 years. The NSF LTER program is being expanded to include Long-Term Ecological Research sites in Land/Ocean Margin Ecosystems. This network of sites will encompass a wide range of freshwater and tidal forcings and geomorphology, watershed land-use types, and aquatic and terrestrial biogeographic provinces and climatic regions. Such programs have been instrumental is assessing coastal ecological system responses to ENSO and other long term climactic variability.

Ocean Floor Observations. Understanding the causal linkages and covariations among the physical, chemical, and biological components of mid-ocean ridge volcanic and hydrothermal systems, and the long-term temporal evolution of these systems is central to a number of on-going and planned programs. Programs are currently being conducted at six sites; three on the Juan de Fuca Ridge in the northeast Pacific Ocean, one on the East Pacific Rise off southern Mexico, one on the East Pacific Rise off northern Peru, and one on the Mid-Atlantic Rise south of the Azores. These programs presently involve long-term temporal observations via repeat visits. Several of the programs are expected to evolve into permanent, real-time observatories in the future.

Techniques for geodetic monitoring of seafloor motions have been developed by combining precision Global Positioning System (GPS) and acoustic ranging techniques. These techniques are valuable for crustal deformation studies because about 70 percent of the Earth's surface is covered by water, and these regions contain most of the Earth's tectonic plate boundaries and zones of crustal deformation. Four programs are on-going or planned. One such program off the south coast of the Island of Hawaii, will monitor the southward motion of the submarine part of the south flank of Kilauea volcano on Hawaii. The 1975 Kalapana magnitude 7 earthquake and subsequent tsunami were the result of motion on the submarine flank of Kilauea. This program will greatly increase understanding of the structure and dynamics of the island and the ability to predict future events.

Ocean Observations of Past Changes. The Earth's climate system varies on time scales longer than the instrumental record, from the major changes of glacial/interglacial cycles to the recently-identified millenial cycles of the North Atlantic and the decadal oscillations of the North Pacific. In order to capture the full natural variability of the system, we need highly-resolved records spanning hundreds or even thousands of years. Such "paleo" time-series are preserved in oceanic sediments and other geo-archives such as massive corals.

Future areas of emphasis include:
1) Global network of tropical-subtropical coral records of sea-surface temperature at seasonal resolution spanning the last 200 years, to identify decadal variability in each region, and to determine correlations and interactions (if any) between regions. For example, the interaction of the ENSO cycle with that of the North Atlantic Oscillation, or with that of the Indian monsoon.
2) Search for evidence of century-millenial cycles outside the North Atlantic, and precise dating of such events to determine global linkages. For example, are the North Atlantic events a cause or a consequence of variations in the Southern Ocean?

NASA Elements

NASA's Earth Science Enterprise [http://www.earth.nasa.gov] remote sensing missions provide a wealth of information that contribute to ocean programs at a fundamental level.

Sea Level. The TOPEX/Poseidon and Jason-1 altimetry missions will provide high quality sea level estimates for interpretation in climate studies. Sea surface height (SSH) data provide information about the ocean geostrophic flow-field near surface and when assimilated into an ocean circulation model, in the interior ocean as well. SSH data also provide a measure of upper ocean heat and haline variability. NASA and CNES have combined forces to build and operate altimetric missions for obtaining high accuracy SSH data since August 1992. Jason-1 will be the follow-on mission to TOPEX/Poseidon and is slated for launch in May 2000. [http://topex-www.jpl.nasa.gov]

Surface Vector Winds over the Ocean. Seawinds instruments on the QuikSCAT and ADEOS-II satellites provide estimates of vector wind over the ocean. Wind stress is the primary mechanical forcing function of the ocean circulation. Remote sensing observations of surface winds are the only way to assure a truly global coverage of wind data over the ocean and to assure that meteorological models provide high-quality wind-stress fields. NASA launches its Seawinds scatterometer on the QuikSCAT mission in mid-1999 to provide 25-km resolution of vector surface winds over 90% of the ice-free ocean each day. A second Seawinds instrument is slated for launch in late 2000 on the Japanese ADEOS-2 satellite. [http://seawinds.jpl.nasa.gov]

Sea Surface Temperature. Sea surface temperature is now delivered operationally using a combination of AVHRR data from NOAA satellites and in situ data for calibration. NASA's new technology delivering sea surface temperature includes the MODIS instrument on EOS AM and PM platforms and microwave (all-weather) temperatures from the NASA/NASDA Tropical Rainfall Measurement Mission. [http://ltpwww.gsfc.nasa.gov/MODIS/MODIS.html]

Ocean Color. The concentration of chlorophyll in the upper ocean layer can be deduced from relatively small contrasts in ocean color. While absolute calibration of such contrast measurements carried out with different instruments may be a challenge, easily observable fast space-time variations provide valuable insight into the dynamics of primary production and the processes that control it. Such ocean color measurements will be provided more or less systematically by a number of satellite missions and operational programs, including NASA/SeaWiFS, ESA/ENVISAT, NASDA/ADEOS-2, NASA/EOS AM-1 and PM-1, and eventually NPOESS (beginning around 2009). [http://seawifs.gsfc.nasa.gov]

Gravity. Gravity Recovery and Climate Experiment (GRACE) satellite is slated for launch in March 2001. It will provide a high accuracy measurement of the time varying gravity field. Knowledge of the marine geoid is fundamental for using altimeter data to study the absolute ocean currents. This mission also provides information about variable deep ocean currents which is complimentary to that obtained >from altimetry. [http://essp.gsfc.nasa.gov/esspmissions.html]

Salinity. NASA is currently developing the technology to remotely sense the ocean surface salinity from low earth orbit. The scientific issues are succinctly discussed in a report of the Salinity and Sea Ice Working Group. [http://www.esr.org/lagerloef/ssiwg/ssiwgrep1.v2.html]

Sea Ice. Sea-ice concentrations (percent areal coverages) to a resolution on the order of 30km have been obtainable from satellites since the early 1970's using passive microwave radiometer technology. The record from the early and mid 1970's contains many large data gaps, but since Oct. 1978 is reasonably complete in terms of obtaining a consistent global sea ice coverage dataset every 1-3 days. This record demonstrates significant seasonal and interannual variability in the sea-ice cover and its dynamics. This dataset is currently being continued with the DMSP Special Sensor Microwave/Imager (SSM/I) and will be further continued with the Advance Microwave Scanning Radiometer (AMSR) on both the EOS-PM platform and the Japanese ADEOS-II platform, both scheduled for launch in the year 2000. [http://wwwghcc.msfc.nasa.gov/AMSR/].

Department of Energy Elements

The Department of Energy, Biological and Environmental Research (DOE-BER) supports peer-reviewed research in marine biology and oceanography relating to the impact of anthropogentic CO_2 on global warming. DOE also supports technology development that underpins new global ocean observational capabilities. Examples of specific programs include:

- Marine Biotechnology — the application of the tools of modern molecular biology to linkages of carbon and nitrogen cycles.
- Synthesis of Global CO_2 Data (with NOAA) — development of tools and models to synthesize the existing data set on ocean CO_2, and related parameters.
- Quality Assurance of CO_2 Survey Data — QA/QC and dissemination of CO_2 data through the Carbon Dioxide Information Analysis Center.
- Carbon Sequestration in the Ocean — establishment of center(s) of excellence as part of the Climate Change Technology Initiative.

Environmental Protection Agency Elements

Many coastal ocean observation elements are carried out by EPA's research laboratories and program offices, as well as by federal, state and local governments, and private entities under EPA's jurisdiction.

<u>Observations to ensure compliance with legislative mandates and regulatory requirements.</u> The Ocean Dumping and Ocean Discharge Programs were initiated to ensure that the disposal of dredged materials and treated wastewater will not adversely impact the marine ecosystems. Potential impacts include problems associated with eutrophication, pathogens and toxics that result in adverse effect on human health and biological integrity of the coastal waters, as well as habitat modification and loss. Observations include quality of dredged materials or treated wastewater, and the physical, chemical, and biological conditions of the marine environment in the vicinity of the disposal or discharge area.

The National Water Quality Inventory requires that states report water quality conditions to EPA for compilation into National Water Quality Inventory Reports to Congress. The information submitted by the states is prepared according to monitoring results of the water quality of waters, including estuarine and coastal waters. The water quality includes physical, chemical, and biological conditions.

<u>Observation to enhance the understanding of the Marine ecosystems.</u> The Environmental Monitoring and Assessment Program (EMAP) is a collaboration between EPA and NOAA for long-term, integrated monitoring, research, and assessment to determine the condition of our nation's ecological resources. EMAP's goal is to develop the scientific understanding for translating environmental monitoring data from multiple spatial and temporal scales into assessments of ecological condition and forecasts of the future risks to the sustainability of our natural resources. This research supports the National Environmental Monitoring Initiative of the Committee on Environment and Natural Resources. EMAP implements monitoring programs that operate on regional scales, emphasizing different ecological resource categories, over periods of years to decades, including five monitoring activities: (1) completion of the Mid-Atlantic Integrated Assessment Geographic Initiative; (2) initiation of the Western Pilot Geographic Initiative; (3) planning for a National Coastal Survey; (4) developing probabilistic coastal monitoring in all coastal states; and (5) establishment of an interagency (EPA, NOAA and NASA) effort to develop an intensive coastal site network of monitoring and research locations throughout the United States.

The Gulf of Maine Program consists of several projects, including a pilot multi-jurisdictional monitoring program, a marine debris control program in a few ports, and preparation of an inventory of contaminant loading from point sources, and identification of critical habitats.

Observation for assisting in watershed and regional planning. The National Estuary Program (NEP) was established by Congress to restore and preserve these unique bodies of water. The program currently includes 28 estuaries that represent 42% of the shoreline of the continental U.S. These programs are in various stages of design and implementation. Each individual estuary program inventories existing Federal, State, local and volunteer monitoring programs in their area and integrates relevant components of these on-going activities into their own monitoring plans according to EPA guidance. Each NEP is developing its own database management system.

The Chesapeake Bay Program was begun in 1984 by the Chesapeake Bay Executive Council. It is a Bay-wide EPA/state cooperative effort. Comprising over 165 stations below the fall line, the program combines efforts of Maryland, Pennsylvania, Virginia, the District of Columbia, several federal agencies, 10 institutions, and over 30 scientists. Nineteen physical, chemical, and biological characteristics are monitored 20 times a year in the main stem of the bay and its many tributaries. A volunteer citizen monitoring program was started in 1985.

The Great Lakes National Program brings together Federal, state, tribal, local, and industry partners in an integrated, ecosystem approach to protect, maintain, and restore the chemical, biological, and physical integrity of the Great Lakes. The program monitors Lake ecosystem indicators; manages and provides public access to Great Lakes data; and helps communities address contaminated sediments in their harbors.

The Gulf of Mexico Program supports many State and local monitoring efforts. An integrated coastal monitoring and assessment program for the Gulf of Mexico is currently being developed, with four main focus areas: excessive nutrient enrichment; public health associated with seafood consumption and recreational use; habitat loss; and non-indigenous species introduction.

New Initiatives. The Clean Water Action Plan is a multi-agency initiative to speed the restoration of our nation's waterways. One major component is development of a Coastal Research Strategy involving coordinated monitoring of coastal waters and a report to the public on the condition of the nation's coastal waters by the year 2000.

Coral Reef Monitoring has been initiated by EPA to determine the cause of reef decline. Results will be used to assess these communities and to identify indicators of degrading environmental conditions.

An Air Deposition Initiative was established in 1995 by EPA's Office of Water to work with EPA's Air Program and other partners to identify and characterize air deposition problems with greater certainty and examine solutions to address them. To date, most efforts have focused on better understanding the links between nitrogen and mercury emissions and harmful effects on water quality and the environment. Much of the recent concern has focused on the deteriorating water quality along our coasts.

U.S. Geological Survey Elements

As the Nation's primary natural and earth science research and information agency, the U.S. Geological Survey maintains a long tradition of providing "Earth Science in the Public Service" (details are included on the web site: http://www.usgs.gov). USGS research is focussed on the four themes of terrestrial and marine geology, water, biology, and terrestrial topographic mapping.

Most of the marine geology and ocean sciences research is conducted through the USGS Coastal and Marine Geology Program which addresses issues in environmental quality, geologic hazards (coastal erosion, earthquakes, tsunamis, landslides), and resources (energy, minerals, gas hydrates). Long-term goals of the program are to develop predictive capabilities to increase scientific understanding of systems to aid long-term planning and management in the coastal ocean, to provide a comprehensive source of scientific information that can be easily accessed and used by the government and the public, and to facilitate scientific research.

Data and information are available through publications and maps, and on the web at (http://marine.usgs.gov). Some of the USGS's water and biologic research relates to marine and ocean regions as well.

Appendix 2: Examples of Pilot Projects for the Observing System

Array for Real-time Geostrophic Oceanography (ARGO). The primary practical goal of ARGO will be to provide an enhanced real-time capability for measurement of temperature and salinity through the upper 2000 m of the ocean and contribute to a global description of the seasonal cycle and interannual variability of the upper ocean thermohaline circulation. Each profiling float is expected to gather up to 100 profiles of temperature and salinity over a lifetime of 3 to 4 years. Technology improvements continue to improve cost-effectiveness. This pilot project is proposed for the period 2003-2005. It is endorsed by the WCRP, GOOS, GCOS, and the Committee on Earth Observing Satellites, comprised of national space agencies.

Integrated within the overall framework of the global ocean observing system, ARGO will strengthen the complementary nature of the direct and remote observing systems, fill large gaps that presently exist in the global sampling network, provide essential information for ocean state estimation, enhance studies of climate variability on interannual time scales, and deliver information for initialization of climate predictions and studies of climate predictability. The drift estimates from such an array would in addition provide useful estimates of deep pressure fields (reference level).

The combination of ARGO and altimetry will generate new applications, including global maps of sea level of time scales of weeks to several years and knowledge of the vertical dependence of the oceanic response to surface forcing. Global ocean and climate models will be initialized, tested, and constrained with a level of information hitherto not available. This network could serve as a foundation for future studies of climate variability and predictability.

Experience gained with observing systems in other climate experiments, on newly gained knowledge of variability from the TOPEX/Poseidon altimeter, and on estimates of the requirements for climate and high-resolution ocean models suggest that a broad-scale array with 200 to 300 km resolution is capable of resolving important global climate signals. The design must be evolved as further experience and knowledge are gained.

Atlantic Circulation and Climate Experiment (ACCE). The Atlantic Circulation and Climate Experiment (ACCE) represents the last field phase of the World Ocean Circulation Experiment (WOCE). During ACCE, approximately 250 profiling floats have been deployed in the Atlantic Ocean north of 6°S. The floats are to provide data to study (1) the role of the upper ocean in driving sea-surface temperature variability; (2) the mid-depth ocean circulation at a nominal depth of 1000 m; and (3) the formation of several North Atlantic mode waters. Practical goals of ACCE include establishing effective monitoring strategies for upper layer temperature and salinity fields and providing data for initialization and verification of climate forecast models. To date, the majority of the ACCE float temperature data have been made available to modelers in near real-time through the Global Telecommunications System. The value of the data in both the initialization process for climate forecast models and scientific research and their complementary to existing in situ and remote upper ocean monitoring strategies will be evaluated. This evaluation will provide, in part, the rationale for or against using floats in a long-term sustained observing system.

Global Ocean Data Assimilation Experiment (GODAE). The Global Ocean and Climate Observing Systems, together with the space agencies' Committee on Earth Observing Satellites, have proposed the Global Ocean Data Assimilation Experiment, a pilot project to carry out a multi-year assimilation of in situ and remotely-sensed physical data using a global numerical ocean circulation models. The main objectives of GODAE are: 1) the application of state-of-the-art ocean models and assimilation methods for short-range open-ocean forecasts, for boundary conditions to extend predictability of coastal and regional subsystems, and for initial conditions of climate forecast models, and 2) to provide global ocean analyses and re-analyses for developing improved understanding of the oceans, improved assessments of the predictability of ocean systems, and as a basis for improving the design and effectiveness of the global ocean observing system.

This pilot is proposed for the 2003-2005 time frame because of the confluence of satellite observations planned for that period. Enhancements to the in situ observations are also sought during that period. It is partly in support of this global ocean data assimilation experiment that the pilot project, an Array for Real-time Geostrophic Oceanography, is proposed to obtain profiles of temperature and salinity throughout the global ocean.

Long-term Ecosystem Observatory at 15-m depth (LEO-15). As part of a commitment by Rutgers University to obtain high resolution, long-term measurements from a broad corridor of marine and coastal habitats, from the watershed of the Mullica River Estuary to the deep sea, the first of a series Long-term Ecosystem Observatories, or LEOs was established on the inner continental shelf off New Jersey (von Alt and Grassle, 1992; von Alt et al., 1997). The goals for a site centered at 15 m depth were to provide: 1) continuous observations at frequencies from seconds to decades, under all conditions, 2) spatial scales of measurement from millimeters to kilometers, 3) practically unlimited power and broad bandwidth, two-way transmission of data and commands, 4) an ability to operate in storms, 5) an ability to plug in any type of new sensor, including cameras, acoustic imaging systems, and chemical sensors and to operate them over the Internet, 6) bottom-mounted winches cycling instruments up and down in the water, either autonomously or on command, 7) docking stations for a new generation of autonomous robotic vehicles to download data and repower batteries, 8) an ability to assimilate data into models and make three-dimensional forecasts for the oceanic environment, 9) means for making the data available in real time to schools and the public over the Internet, and 10) low cost relative to the cost of building and maintaining manned above- and below-water systems. These objectives were achieved during the summer, 1998 period of intensive operations at LEO-15.

A 10 km electro-optic cable links two long-term outposts or nodes to Rutgers' shore-based marine laboratory and forms the basis for a real-time connection between the undersea world off the coast of New Jersey and the Internet. The cable provides continuous and ample electrical power. A fiber-optic telemetry system and microprocessors are capable of switching power and signal channels among the various undersea connectors on the nodes, and they control bi-directional communication and video links over three optical fibers. A bottom-mounted winch, also controlled over the Internet, moves an instrument package, with sensors that monitor salinity, temperature, oxygen, light, chlorophyll, optical back scatter, and depth, up and down in the water column. Frequent profiles yield a near continuous plot of vertical structure of the ocean vs. time. Video, sound, currents, wave height and period, and parameters related to sediment transport are routinely measured from bottom instruments. Free-swimming, torpedo-shaped, autonomous vehicles called REMUS (Remote Environmental Sensing UnitS) swim out from docking stations connected to the LEO-15 system (von Alt and Grassle, 1992: von Alt et al., 1994). REMUS can be programmed from the laboratory to follow a course to explore phenomena detected by satellites in space or high-frequency radar shore stations. The REMUS returns to the docking station, downloads data, and repowers batteries. Boats and divers visit the site on days when the weather is good, and a satellite dish provides broad-coverage of sea surface characteristics (temperature and ocean color when it is not cloudy, and surface roughness). Shore stations using high-frequency radar provide patterns of surface currents, and provide data on weather in the immediate vicinity of LEO-15. LEO-15 provides a continuous subsea data feed into a coastal ocean forecast system on shore (Glenn et al., 1998).

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Pilot Research Moored Array in the Tropical Atlantic (PIRATA). The Pilot Research Moored Array in the Tropical Atlantic (PIRATA) project is a joint Brazil, France, U.S. program. PIRATA is a three-year demonstration project with the following scientific goals: to provide an improved description of seasonal-to-interannual variability in upper ocean and air-sea interface; to improve understanding of the processes that induce SST variability; and to provide a data-set to be used to develop and to improve predictive models of the coupled Atlantic climate system. The technical goals of PIRATA are to implement a pilot array of moored buoys in the tropical Atlantic and to collect and transmit the data in real-time. An array of 14 moored buoys will be deployed during the years 1997 to 2000 for monitoring surface variables and upper ocean thermal structure at key locations in the tropical Atlantic. The purpose of the array is to demonstrate scientific success in a limited geographical region for a limited duration of time, as a guide to a more serious long range planning.

Appendix 3: Major Data Management Systems

- International Oceanographic Data & Information Exchange (IODE) of UNESCO, see http://ioc.unesco.org/iode/index.htm
- GCOS-13 (WMO/TD-No. 677), GCOS Data and Information Management Plan, Version 1.0, April 1995, see http://193.135.216.2/web/gcos/pub/dim_v1_1.html
- The Joint Data and Information Management Plan of GOOS, GTOS, and GCOS, described in GOOS Publication no. 42, The GOOS 1998, IOC, Paris, 168 pp.
- The STORET system of EPA, see http://www.epa.gov/owow/STORET
- The EOS Data and Information System (EOSDIS) project of NASA, see http://spsosun.gsfc.nasa.gov/NewEOSDIS_Over.html
- The National Oceanographic Data Center of NOAA/NESDIS, see http://www.nodc.noaa.gov/
- The Master Environmental Library of the Department of Defense, see http://www-mel.nrlmry.navy.mil/
- The Naval Oceanographic Office suite of ocean data and products, see http://128.160.23.51/noframe/select.products.htm
- The data system for the Tropical Atmosphere Ocean (TAO) array, see http://www.pmel.noaa.gov/toga-tao/review98/data.html
- Lists of oceanographic data servers at http://gcmd.gsfc.nasa.gov/pointers/ocean.html
- The Distributed Oceanographic Data System (DODS) from the University of Rhode Island and the Massachusetts Institute of Technology, see http://rs.gso.uri.edu/DODS/home/home.html
- The World Ocean Circulation Experiment (WOCE) of the NSF has a data information unit, see http://www.cms.udel.edu/woce/
- Metadata (i.e., data about data) requirements of the Federal Geographic Data Committee, see http://www.fgdc.gov/metadata/metadata.html

Appendix 4: Acronyms

ADEOS-II	Advanced Earth Observing Satellite-II (Japan)
ARGO	Array for Real-time Geostrophic Oceanography
AUV	Autonomous Underwater Vehicle
AVHRR	Advanced Very High Resolution Radiometer
C-MAN	Coastal Marine Automated Network
CARICOMP	Caribbean Coastal Marine Productivity
CENR	Committee on Environment and Natural Resources
CISNet	Coastal Intensive Site Network
CLIVAR	Climate Variability and Predictability Program
CMED/GMNET	Consortium for Marine and Estuarine Disease/Gulf of Mexico Network
CNES	Centre National d'Études Spatiales (France)
CORE	Consortium for Oceanographic Research and Education
DoD	Department of Defense
DODS	Distributed Oceanographic Data System
DOE	Department of Energy
ECDIS	Electronic Chart and Display Information Systems
EEZ	exclusive economic zone
EMAP	Environmental Monitoring and Assessment Program
ENSO	El Niño-Southern Oscillation
EOSDIS	EOS Data and Information System
EPA	Environmental Protection Agency
ERS-1	European Remote Sensing satellite-1
ERS-2	European Remote Sensing satellite-2
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
FCCC	Framework Convention on Climate Change
FGDC	Federal Geographic Data Committee
GCOS	Global Climate Observing System
GIS	Geographic Information System
GLOBEC	Global Ecosystems project
GLORIA	Geological Long-Range Inclined Asdic
GNP	Gross National Product
GODAE	Global Ocean Data Assimilation Experiment
GOES	Geostationary Operational Environmental Satellite
GOOS	Global Ocean Observing System
GTOS	Global Terrestrial Observing System
HAB	harmful algal bloom
IGBP	International Geosphere-Biosphere Program
IGOS	Integrated Global Observing System
IOC	Intergovernmental Oceanographic Commission
IODE	International Oceanographic Data & Information Exchange
IPCC	Intergovernmental Panel on Climate Change
LATEX	Louisiana-Texas shelf study
LEO	Long-term Ecosystem Observatory

LEO-15	Long-term Ecosystem Observatory at 15-m depth
LTER	Long-term Ecological Research
MAROB	Marine Observation
MetOp	Meteorological Operational (satellite)
MMS	Minerals Management Service
NAML	National Association of Marine Laboratories
NASA	National Aeronautics and Space Administration
NAWQA	National Water Quality Assessment program
NDBC	National Data Buoy Center
NEP	National Estuary Program
NERR	National Estuarine Research Reserves program
NESDIS	National Environmental Satellite, Data and Information Service
NGO	non-governmental organization
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NOPP	National Oceanographic Partnership Program
NORLC	National Ocean Research Leadership Council
NOS	National Ocean Sciences
NPOESS	National Polar-Orbiting Environmental Satellite System
NRC	National Research Council
NS&T	National Status and Trends
NURP	National Undersea Research Program
NVODS	National Virtual Ocean Data System
NWP	numerical weather prediction
NWS	National Weather Service
OOPC	Ocean Observations Panel for Climate
OOSDP	Ocean Observing System Development Panel
ORAP	Ocean Research Advisory Panel
PDO	Pacific Decadal Oscillation
PIRATA	Pilot Research Array in the Tropical Atlantic
PORTS	Physical Oceanographic Real-Time System
PORTS/VTS	PORTS/Vessel Traffic Services
QC	Quality Control
R&D	Research and Development
SeaWiFS	Sea-viewing Wide Field-of-view Sensor
SST	Sea Surface Temperature
TAO	Tropical Atmosphere-Ocean
T/P	TOPEX/Poseidon
UNCLOS	United Nations Convention on the Law of the Sea (Montego Bay, 1982)
UNESCO	United Nations Educational, Scientific, and Cultural Organization
USCG	U.S. Coast Guard
USGS	U.S. Geological Survey
VOS	Volunteer Observing Ships
WCRP	World Climate Research Program
WES	Waterways Experiment Station

WHOI	Woods Hole Oceanographic Institution
WOCE	World Ocean Circulation Experiment
XBT	expendable bathythermograph

Appendix 5: Contributors to Preparation of this Document

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